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Geotextiles for Drainage, Gas Venting, and Erosion Control at Hazardous Waste Sites

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16. ABSTRACT

This document provides information on the properties of geotextiles (engineering fabrics) and on the potential uses of geotextiles at hazardous waste sites. While primarily intended to assist those involved in the design of remedial measures for uncontrolled hazardous waste landfills, the design procedures and criteria set forth could prove equally useful to those designing controlled land disposal facilities. This report is also intended to be a source of technical information to aid regulatory personnel in evaluating designs submitted for approval. Subjects discussed include the types of fabrics and related products currently available, the various functions of these fabrics, test methods for evaluating potential fabric performance, recommended design procedures for using geotextiles and related products in drainage and erosion control systems, and recommended installation procedures for the various applications.

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NOTICE

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Mention of trade names or commercial products is for explanatory purposes only and does not imply specific endorsement by the Environmental Protection Agency of any product or brand in preference to others.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This handbook provides general information on properties and uses of geotextiles, and provides specific guidance for the use of geotextiles for drainage, venting, and erosion control systems at hazardous waste sites. This handbook is primarily intended for those involved in the design of remedial measures for uncontrolled hazardous waste sites. It will also serve as a source of technical information to regulatory personnel in evaluating any such designs submitted for approval

For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

Geotextiles (engineering fabrics) have proved to be effective materials for solving numerous drainage and stability problems in geotechnical engineering, and they can be used to solve similar problems in the containment and disposal of solid and hazardous waste. This handbook provides general information on geotextiles in hazardous waste landfills and provides guidance for the designer in the use of geotextiles for drainage, venting, and erosion control systems.

Important mechanical, hydraulic, and endurance properties of fabrics are discussed. The most important mechanical properties are considered to be tensile strength and elongation, tearing resistance, and puncture resistance, as measured by the grab tensile test, trapezoidal tear test, and puncture test, respectively. Tests for other mechanical properties such as creep susceptibility, frictional and pull-out resistance with soil, and seam strength are also discussed.

The important hydraulic properties of fabrics include their ability to retain fine soil particles (piping resistance) and their ability to resist clogging. These properties are discussed, along with the equivalent opening size (EOS) and gradient ratio (GR) tests used to evaluate these qualities. Possible causes of the long-term reduction of fabric hydraulic flow capacity are discussed.

Consideration is given to fabric resistance to ultraviolet light and chemicals and to biological degradation.

Applications of geotextiles to (1) landfill cover drains, leachate collection systems, and ground-water control systems; (2) gas venting; and (3) protection of waste covers and waste disposal sites from surface erosion are addressed in detail. In each of these applications, design considerations, fabric requirements, and construction techniques are discussed. Model specifications for fabrics in the various applications are given. For drainage systems and erosion control, criteria are presented for the selection of fabrics based on the fabric's piping resistance and clogging resistance. Strength requirements based on the severity of the construction environment and long-term chemical/biological degradation are addressed.

This report was submitted in fulfillment of Interagency Agreement No. AD-96-F-1-400-1 by the U. S. Army Engineer Waterways Experiment Station under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period October 1981 to May 1986.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

AOS -- apparent opening size (see Appendix C)
ASTM -- American Society for Testing and Materials
cm -- centimeter(s)
CRE -- constant-rate-of-extension
°C -- degree(s) Centigrade (or Celsius)
°F -- degree(s) Fahrenheit
EOS -- equivalent opening size (see Appendix C)
ft -- foot, feet
g -- gram(s)
GR -- gradient ratio
in. -- inch(es)
kg -- kilogram(s)
kN -- kilonewton(s)
kPa -- kilopascal(s)
lb -- pound(s)
m -- meter(s)
m^2 -- square meter(s)
mil(s) -- thousandths of an inch
mm -- millimeter(s)
N -- newton(s)
oz -- ounce(s)

ABBREVIATIONS

POA -- percent open area (see Appendix C)

pcf -- pounds per cubic foot

psi -- pounds per square inch

sec -- second(s)

yd^2 -- square yard (s)

SYMBOLS

A -- area

C_u -- coefficient of uniformity. $C_u = D_{60}/D_{10}$

D_{10} -- for a soil, the particle size of which 10 percent of the particles, by weight, are smaller

D_{15} -- for a soil, the particle size of which 15 percent of the particles, by weight, are smaller

D_{50} -- for a soil, the particle size of which 50 percent of the particles, by weight, are smaller

D_{60} -- for a soil, the particle size of which 60 percent of the particles, by weight, are smaller

D_{85} -- for a soil, the particle size of which 85 percent of the particles, by weight, are smaller

i -- hydraulic gradient

k -- coefficient of permeability (hydraulic conductivity)

k_f -- coefficient of permeability (hydraulic conductivity) for fabric

k_p -- coefficient of permeability (hydraulic conductivity) in plane of fabric

k_s -- coefficient of permeability (hydraulic conductivity) for soil

L -- units of length; length between fabric grips

l -- length

SYMBOLS

L_f -- length of flow path; when measuring the permeability of fabrics, L_f is the thickness of the fabric

q -- hydraulic discharge rate

T -- units of time

t -- thickness

W -- width, specimen width

w -- width

Δh -- hydraulic head loss

Ψ -- permittivity

Θ -- transmissivity

1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of this technical handbook is to provide general information on the properties and uses of geotextiles in hazardous waste landfills and to provide specific guidance for the designer in the use of geotextiles for drainage, gas venting, and erosion control systems. Although this handbook is primarily intended to assist those involved in the design of remedial measures for uncontrolled hazardous waste landfills, the design procedures and criteria set forth here should prove equally useful to those designing controlled land disposal facilities. This handbook is also intended to be a source of technical information to aid regulatory personnel in evaluating any such designs submitted for approval. The user must be aware, however, that because of the rapidly expanding technology in geotextiles, the design procedures presented here can be expected to need modification with time. The handbook cannot address the site-specific variables that determine whether a geotextile or some alternative technology should be used to solve a particular problem. Subjects discussed in this handbook include the various types of fabrics and related products currently available, the various functions of these fabrics, test methods for evaluating potential fabric performance, recommended design procedures for using geotextiles and related products in drainage, gas venting, and erosion control systems, and recommended installation procedures for the various applications.

For the purpose of this handbook, the term "geotextile" is defined as any permeable synthetic textile product used in geotechnical engineering. Related products such as plastic grids ("geogrids"), drainage panels, and other composite products are also discussed in this handbook because these products are used in similar applications or include geotextiles as part of their structure.

In Great Britain, the term "membrane" is used to refer to both geotextiles (permeable membranes) and to impermeable plastic films whether or not they have been reinforced with a fabric scrim. In the United States, the generic "geomembrane" has been proposed to designate impermeable membranes used in geotechnical engineering. Since most users of geotextiles continue to refer to them (perhaps for phonetic and orthographic simplicity) as "engineering fabrics" or, simply, "fabrics," the terms, "engineering fabric," "fabric," and "geotextile" will be used interchangeably throughout this handbook.

A glossary of terms related to geotextiles appears in Appendix C.

1.2 Historical Background

Synthetic fabrics appear to have been first used in engineering construction in the United States in 1958, when a woven fabric was substituted for a graded aggregate filter blanket in construction of a shore protection in South Palm Beach, Florida. From that beginning, woven fabric gradually began to replace granular filters in coastal engineering for erosion control and for underdrain applications. In Europe, the mid 1960's saw the introduction of nonwoven fabrics for stabilization of roads and embankments and for erosion protection. The first use of a nonwoven fabric in an earth dam and as a filter in a drainage trench (Giroud, 1981) took place in Europe in 1970; the first use of a fabric in connection with a synthetic membrane took place in 1971 (Giroud, 1982) when a nonwoven fabric was used to protect a synthetic membrane brine pond liner. The increasing use of filter fabrics by the U. S. Army Corps of Engineers throughout the 1960's for levee slope protection and for trench drains led to research at the U. S. Army Engineer Waterways Experiment Station by Calhoun (1972) who published a report that set forth design guidelines for projects of the U. S. Army Corps of Engineers. The mid 1970's saw a rapid expansion in the use of both woven and nonwoven geotextiles by government agencies as well as private firms in all types of geotechnical engineering construction. Tremendous growth in the use of geotextiles led in 1977 to the first international conference on the use of fabrics in geotechnical engineering. It was held in Paris, France. That year also saw the formation of a subcommittee on geotextiles and their applications in the American Society for Testing and Materials (ASTM) Committee D-13 on Textile Products. Later, this subcommittee joined with ASTM Committee D-18 on Soil and Rock to form joint subcommittee D-13.61/18.19, which brought together the interest and expertise of textile engineers with that of geotechnical engineers in the development of standards for evaluating these new products. The most recent development has been the formation in 1984 of ASTM Committee D-35 on Geotextiles and Related Products. Christopher (1983a) reported that the usage of geotextiles has grown from 12.5 million m^2 (15 million yd^2) in 1977 to 115 million m^2 (138 million yd^2) in 1983 in the United States and Canada alone. In spite of this rapidly expanding use of geotextiles, their use and performance in applications related to waste containment and disposal activities have only rarely been documented in the open literature.

1.3 Fabric Types and Constructions

1.3.1 Fabric Materials

Geotextiles are currently being made from polypropylene, polyester, polyethylene, nylon, polyvinylidene chloride, and fiber glass. Some experimental fabrics have been made from Kevlar.[a] Polypropylene and polyester are by far the most used of these materials. The physical properties of these materials can be varied considerably, depending on the additives used in composition and on the methods of processing into filaments and subsequent incorporation into the finished fabric. The tensile strength of polyester and polypropylene filaments can be increased greatly by drawing or stretching the filaments while they are cooling from the molten state. Typical physical property values from the most common polymers are given in Table 1-1.

---

[a] Kevlar is a registered trademark of Du Pont for their aromatic polyamide fiber.

TABLE 1-1

TYPICAL VALUES FOR SOME PHYSICAL PROPERTIES OF COMMON POLYMERS (Bell and Hicks et al., 1980)

Property	Polypropylene	Polyester	Nylon	Polyethylene
Specific gravity	0.9	1.3	1.1	0.9
Melting temperature, °C	175	260	260	135
(°F)	(347)	(500)	(500)	(275)
Water absorption, %	Nil	0.6	2.0	Nil

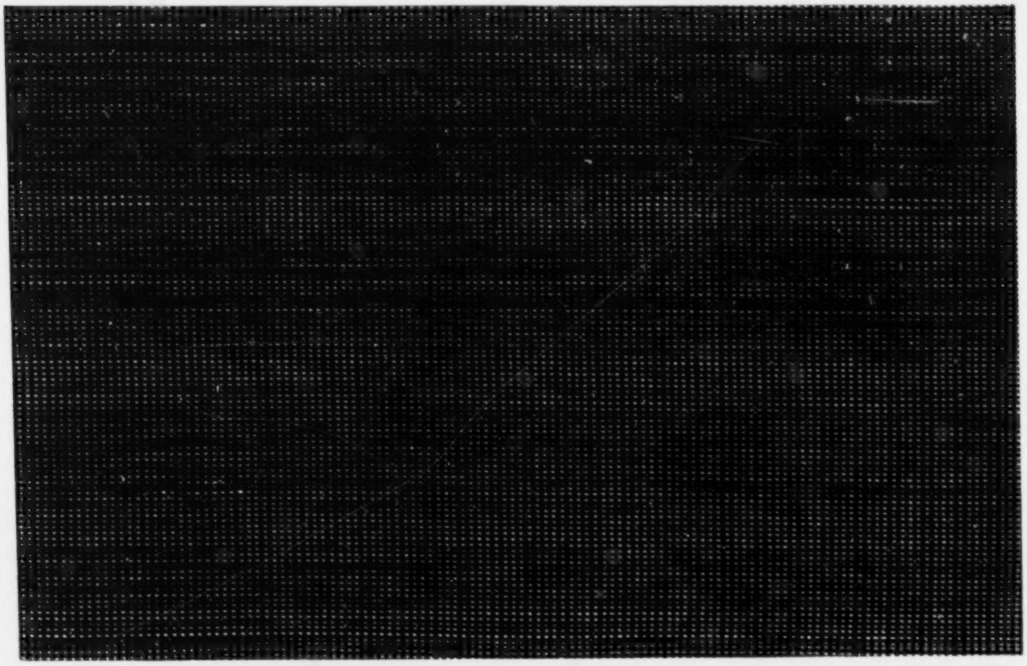
1.3.2 Fabric Construction

In woven construction, the warp yarns, which run in the direction of manufacture and parallel with the long direction of the fabric rolls, are interlaced with fill (or filling) yarns which run perpendicular to the long direction of the fabric roll. This type of construction is the most expensive, but it tends to produce fabrics with relatively high strengths and moduli (ratio of tensile stress to tensile strain) and relatively low elongations at rupture. The modulus, however, depends greatly on the orientation. When woven fabrics are pulled on a bias to the direction of the fibers, the modulus decreases dramatically, although the ultimate breaking strength may increase. Woven construction also produces fabric with a relatively simple pore structure and narrow range of pore sizes or openings between fibers. Woven fabrics are most commonly plain woven, but they are sometimes made by twill weave or leno weave (a very open type of weave). Woven fabrics can be composed of monofilaments (Figure 1-1) or multifilament yarns (Figure 1-2). The monofilament woven fabrics are generally used for filter and some reinforcement applications. These fabrics are often passed between heated rollers after weaving to help stabilize the positions of the filaments and regulate the sizes of the openings in the weave, a process called calendering. The multifilament woven fabrics are usually restricted to reinforcement applications because these fabrics are expensive but have the highest strengths of all fabrics. A different type of monofilament is the slit film or ribbon filament fabric (Figure 1-3). The fibers for this fabric are thin and flat rather than round or nearly round in cross section, and they are made by cutting sheets of plastic into narrow strips. As a result of using flat filaments, these materials do not have uniform openings, and holes may not exist at each crossover. These fabrics are relatively inexpensive among the woven fabrics and are primarily used for separation (i.e., preventing the intermixing of two materials such as aggregate and fine-grained soil). Another special type of fabric is one made from fibrillated, slit-film filaments that have been twisted to make a yarn (Figure 1-4).

The knitting process, in which yarns are looped with each other, is not widely used in the making of geotextiles. Only two fabrics are known to currently be made by this process: One is designed for unidirectional soil

FIGURE 1-1

WOVEN, MONOFILAMENT GEOTEXTILES HAVING LOW-PERCENT OPEN AREA (TOP) AND HIGH-PERCENT OPEN AREA (BOTTOM)



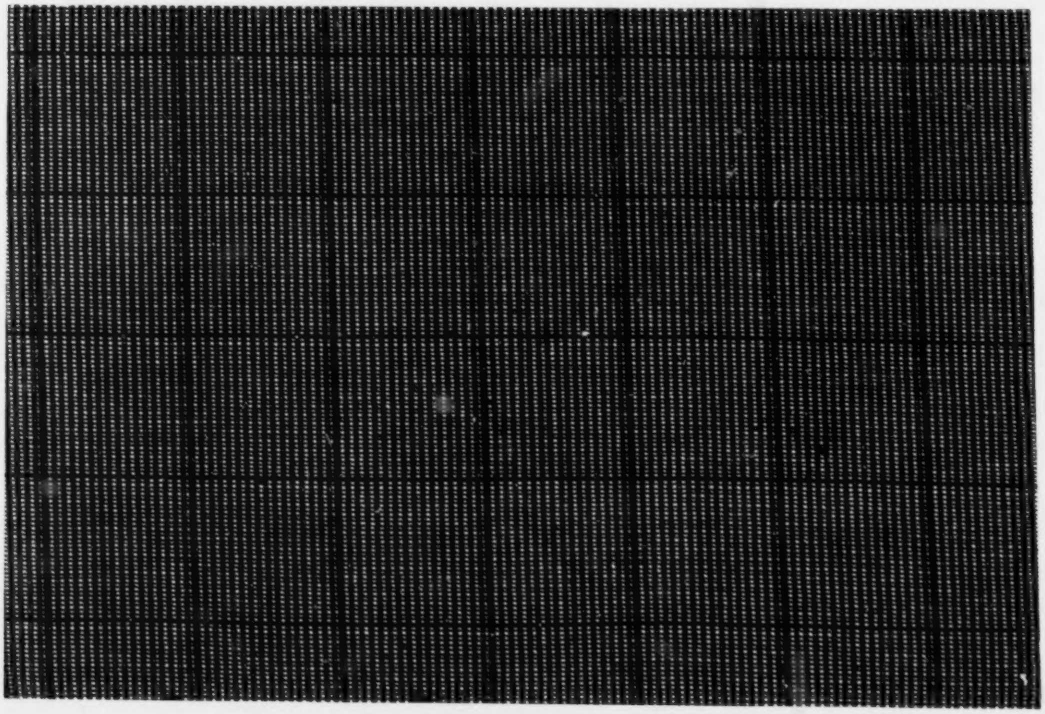
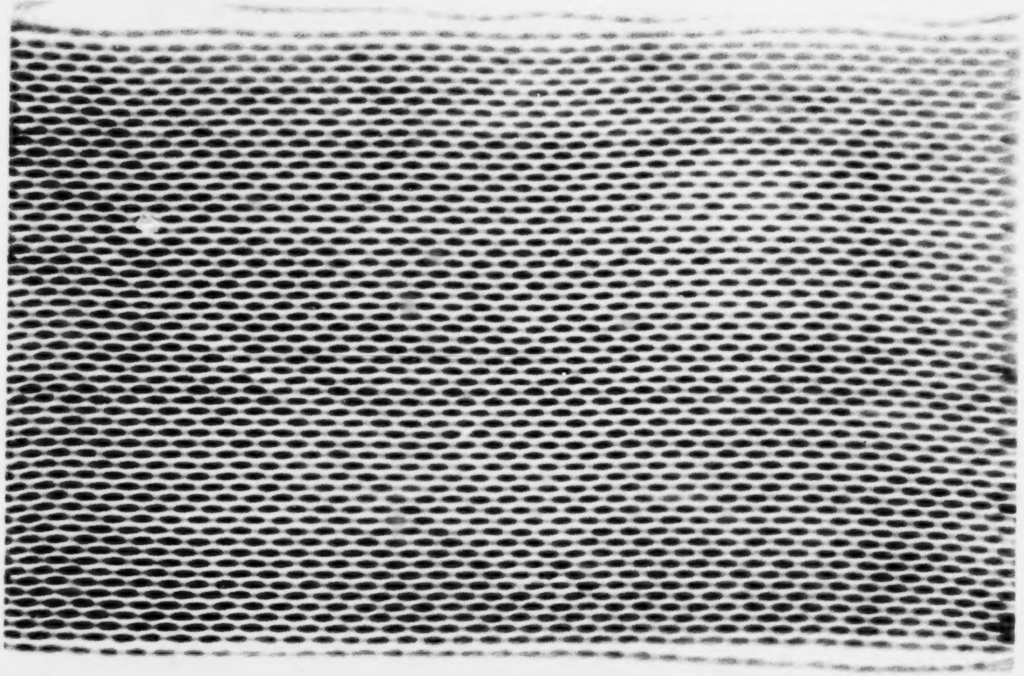


FIGURE 1-2

WOVEN, MULTIFILAMENT GEOTEXTILE



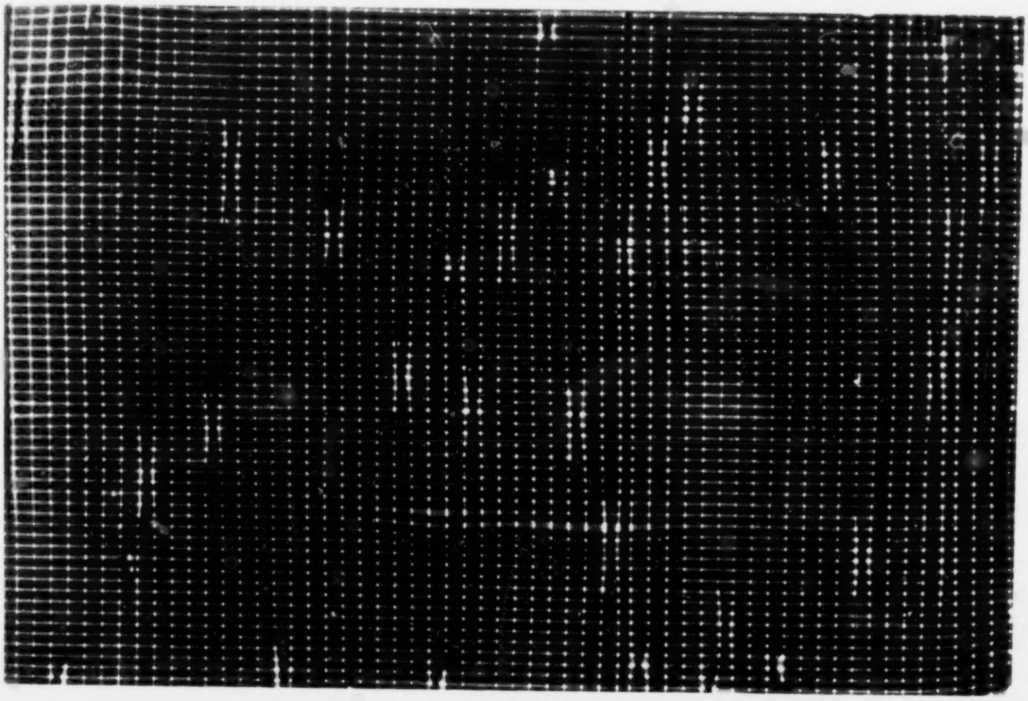
reinforcement, and the other is for temporary surface erosion protection. With knitted fabrics, the strength properties can be varied unidirectionally or multidirectionally. The advantages of the knitting process are that it is less expensive than weaving and it is possible to knit tubular shapes for surrounding drain pipes.

Nonwoven fabrics comprise those fabrics that are formed by some process other than weaving or knitting. These fabrics can be made from either continuous filaments or from staple fibers. In either case, the fibers are laid on a supporting screen or belt to form a mat and then bonded using one of the processes described below. The orientation of the fibers is usually more or less parallel with the plane of the fabric, but depending on the process, the fibers can be randomly oriented in the plane or can be given preferential orientation. In some processes, staple fibers can be given an orientation perpendicular to the plane of the fabric so that the fiber ends are exposed at the surface of the mats. In the spun-bonding process, filaments are extruded, drawn to increase the polymer orientation (and hence strength) and laid on the moving belt or screen as continuous filaments to form the mat, which is then bonded by any one of the processes described below.

a. Needle punching. Bonding by needle punching involves pushing many barbed needles through the fiber mat normal to the plane of the fabric. The process causes the fibers to be mechanically entangled. The resulting fabric has the appearance of a felt

FIGURE 1-3

WOVEN, SLIT-FILM GEOTEXTILES



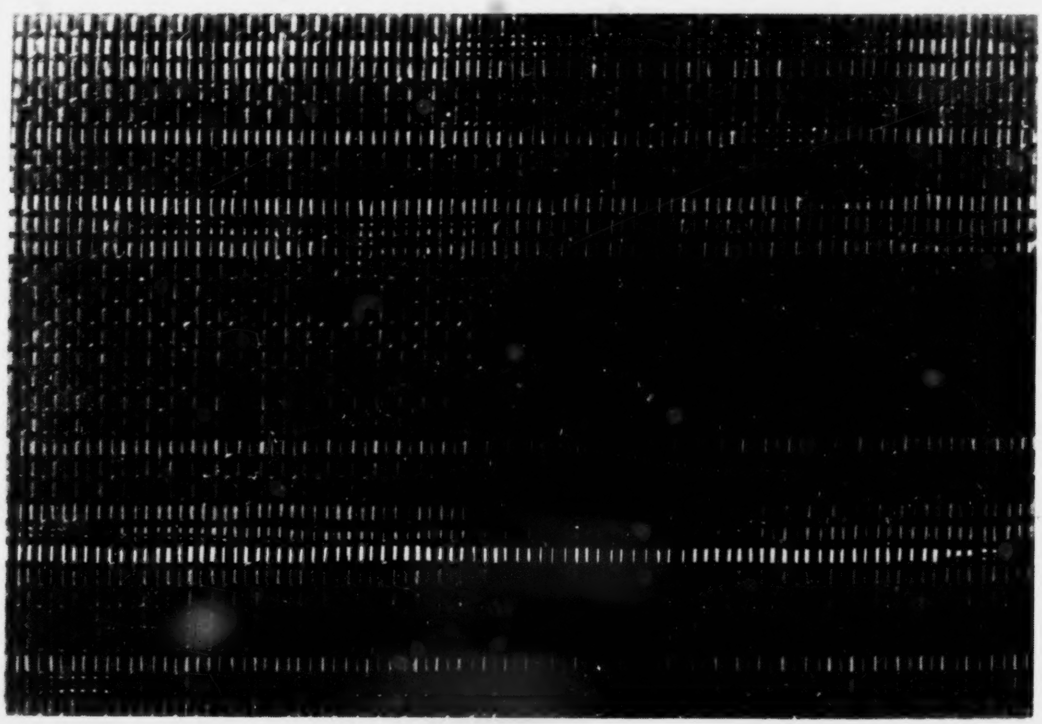
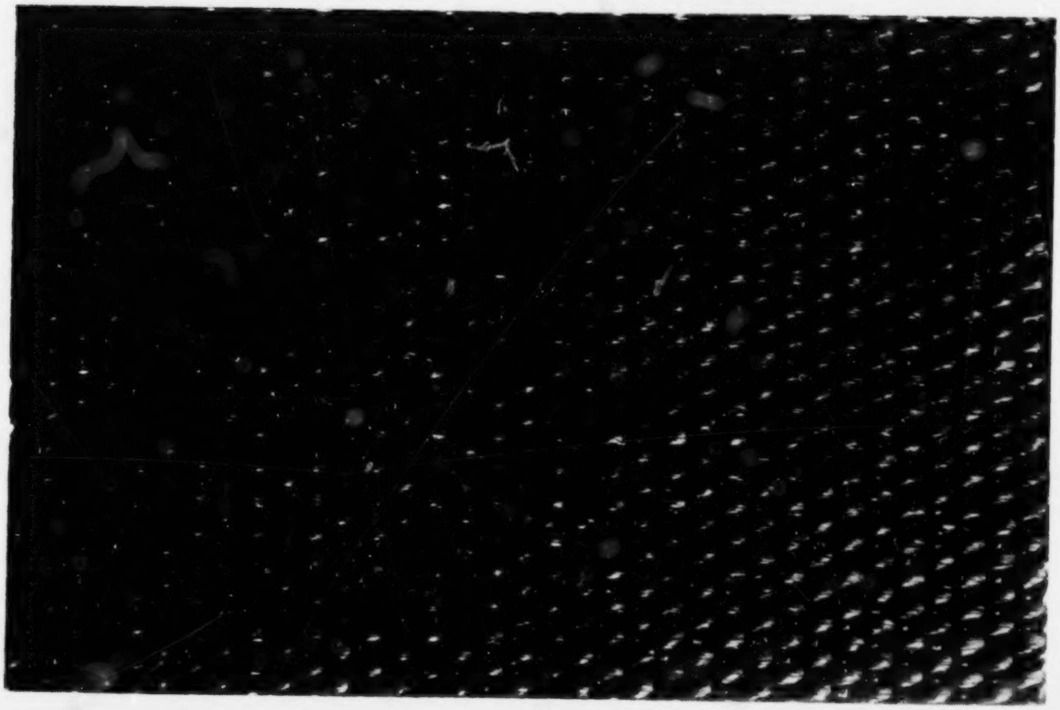


FIGURE 1-4

FIBRILLATED-FILM, WOVEN GEOTEXTILE



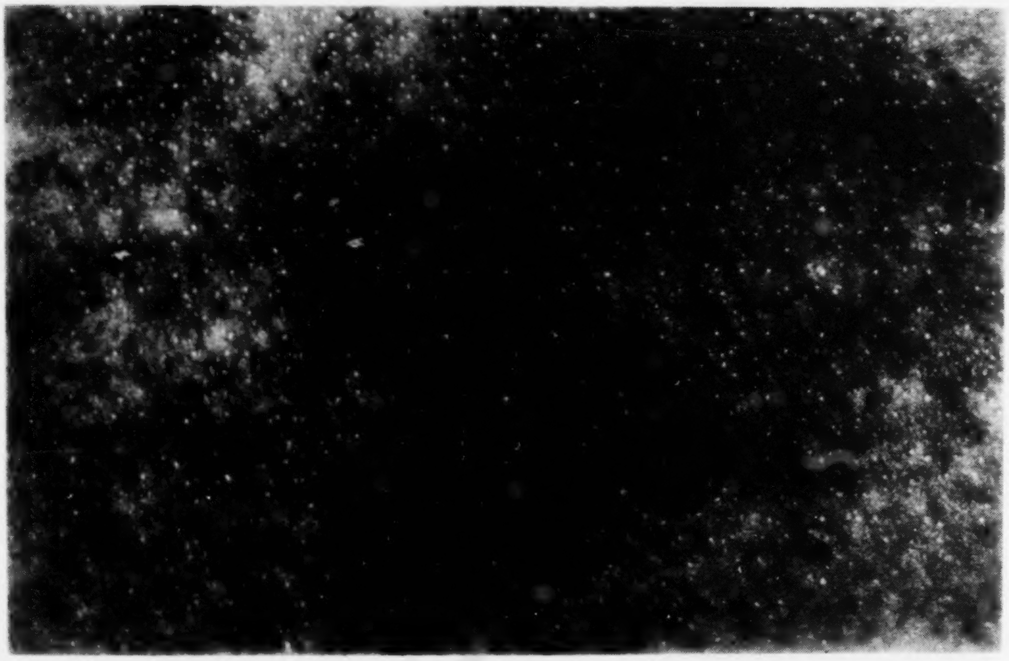
mat. The size of the needles determines the sizes of the largest openings in the fabric, but the complex structure of the matted filaments determines the overall permeability and pore characteristic (see Figure 1-5). Needle-punched fabrics can be formed by needling a single mat thickness or by needling several mat thicknesses together.

b. Heat bonding. In this process, the mat is laid and then the fibers are bonded at some or all of the points where fibers cross one another. This can be done by incorporating fibers of the same polymer type but having different melting points in the mat or by using heterofilaments (i.e., fibers composed of one type of polymer on the inside and covered or sheathed with a polymer having a lower melting point). With heterofilament bonding, up to 100 percent of the fiber crossover points can be bonded, the number of bonds being controlled by the percentage of heterofilaments in the mat. A heat-bonded fabric is shown in Figure 1-6.

c. Resin bonding. Resin is introduced into the fiber mat, coating the fibers and bonding the contacts between fibers. A resin-bonded fabric is shown in Figure 1-6.

FIGURE 1-5

NEEDLE-PUNCHED, NONWOVEN GEOTEXTILE



d. Combination bonding. Sometimes a combination of bonding techniques is used to facilitate manufacture or confer desired properties. Since needle punching tends to leave the fibers relatively free to move with respect to each other, heat or resin bonding can be combined with it to increase the dimensional stability of the fabric. Very open woven fabrics are also sometimes coated to fix filament positions.

Combination fabrics are those that combine two or more of the fabrication techniques previously described. The most common combination fabric is a nonwoven mat that has been bonded by needle punching to a woven scrim (see Figure 1-7). The nonwoven mat may be on one or both sides of the woven backing.

1.3.3 Related Products

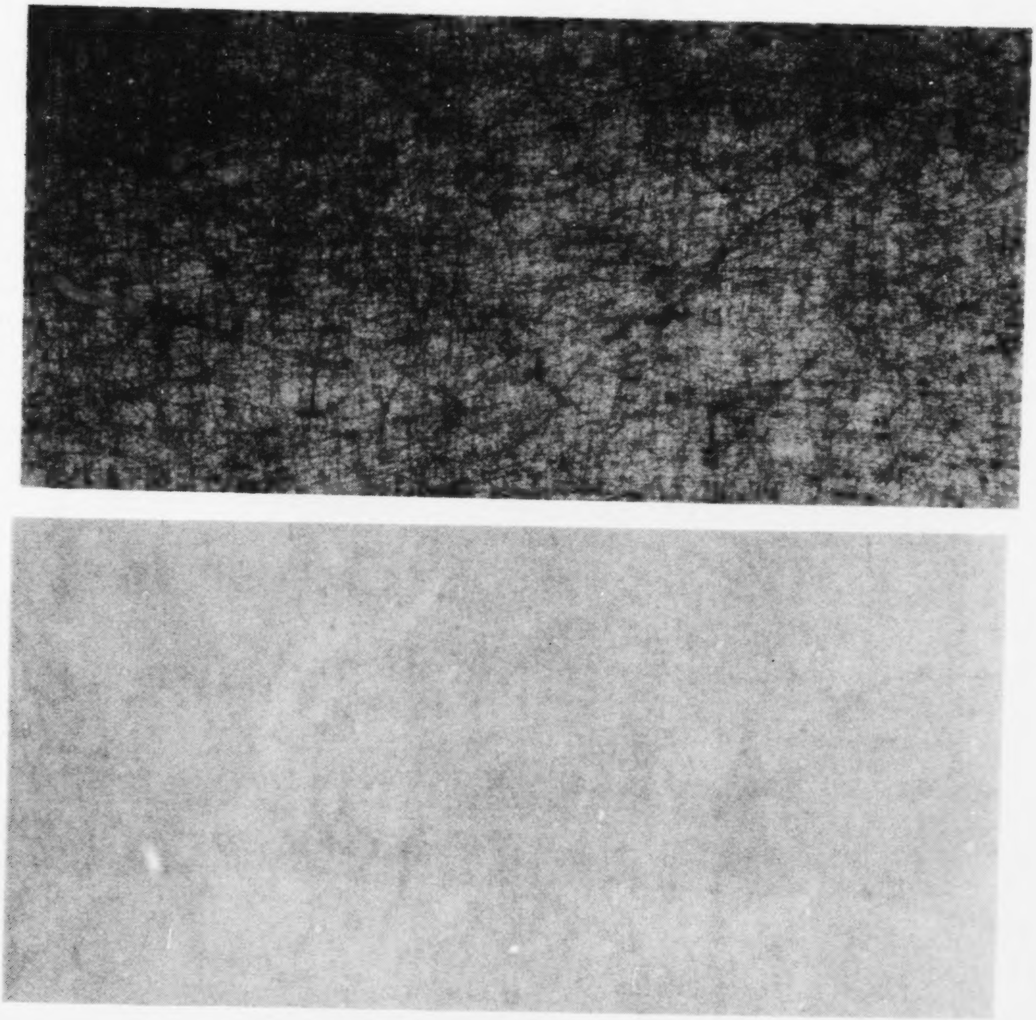
Geotextile-related products consist of grids, mats, strip drains, drainage panels, and fabric forms. These products are discussed here either because they are compound products that incorporate fabric or because they are synthetic materials used in the same ways that engineering fabrics are used.

1.3.3.1 Grids and Mats

Included here are the heavy construction grids or meshes of polyethylene used mostly in soil reinforcement applications and the construction of gabions

FIGURE 1-6

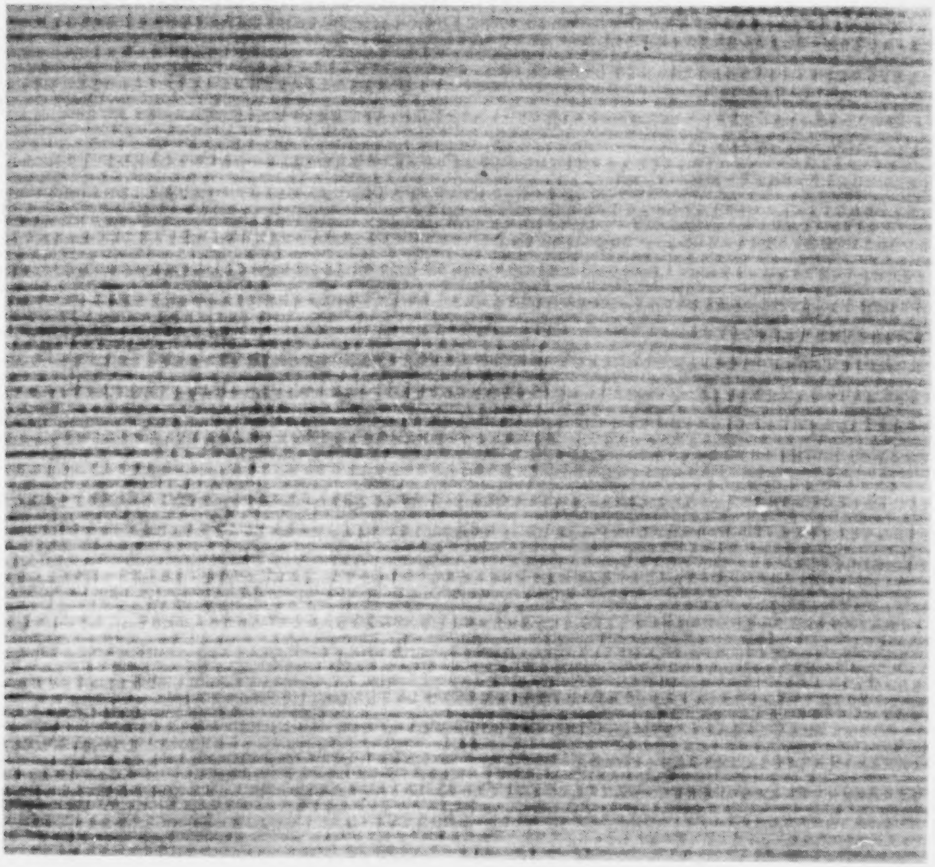
HEAT BONDED NONWOVEN GEOTEXTILE (TOP) AND RESIN BONDED NONWOVEN GEOTEXTILE (BOTTOM)



(see Figure 1-8). The grids are drawn in the manufacturing process to orient the molecular structure and provide high tensile strength. Another product is a thick, open mat composed of crimped and tangled monofilament fibers that are heat-bonded at the contacts to form a three-dimensional network particularly suited for erosion control. Both the mat just described and certain of the grids are also being sandwiched between conventional nonwoven fabrics to create self-contained, subsurface drainage panels. Another special product suited for surface erosion control, particularly during establishment of vegetative cover, is a polypropylene open-knitted netting interlaced with strips of paper. Still another newer product is formed as a mat of very strong composite webbing of polyester filaments sheathed in polyethylene.

FIGURE 1-7

COMBINATION NEEDLED, NONWOVEN AND SLIT-FILM, WOVEN GEOTEXTILE



1.3.3.2 Strip Drains

An expanding use of fabrics is in the construction of strip drains, initially developed to be used as vertical drains to accelerate the consolidation of soft soils. Typically, the strip drains are inserted into the soil using special equipment. Several commercial sources are available in the United States and Canada for this technique. The actual details of fabrication of strip drains vary slightly from one manufacturer to another, but nearly all drains consist of a continuous, channeled, plastic core that is 90 mm to 100 mm (3.5 to 4 in.) wide and surrounded by a fabric or occasionally a heavy paper envelope. The plastic core holds the envelope open while the channels in it provide a conduit for the movement of fluid out of the soil. Two of the available types are shown in Figure 1-9. Strip drains are produced in continuous rolls up to 140 m (450 ft) in length. In the typical

FIGURE 1-8

GRIDS FOR UNIDIRECTIONAL REINFORCEMENT (TOP) AND FOR GABIONS (BOTTOM)

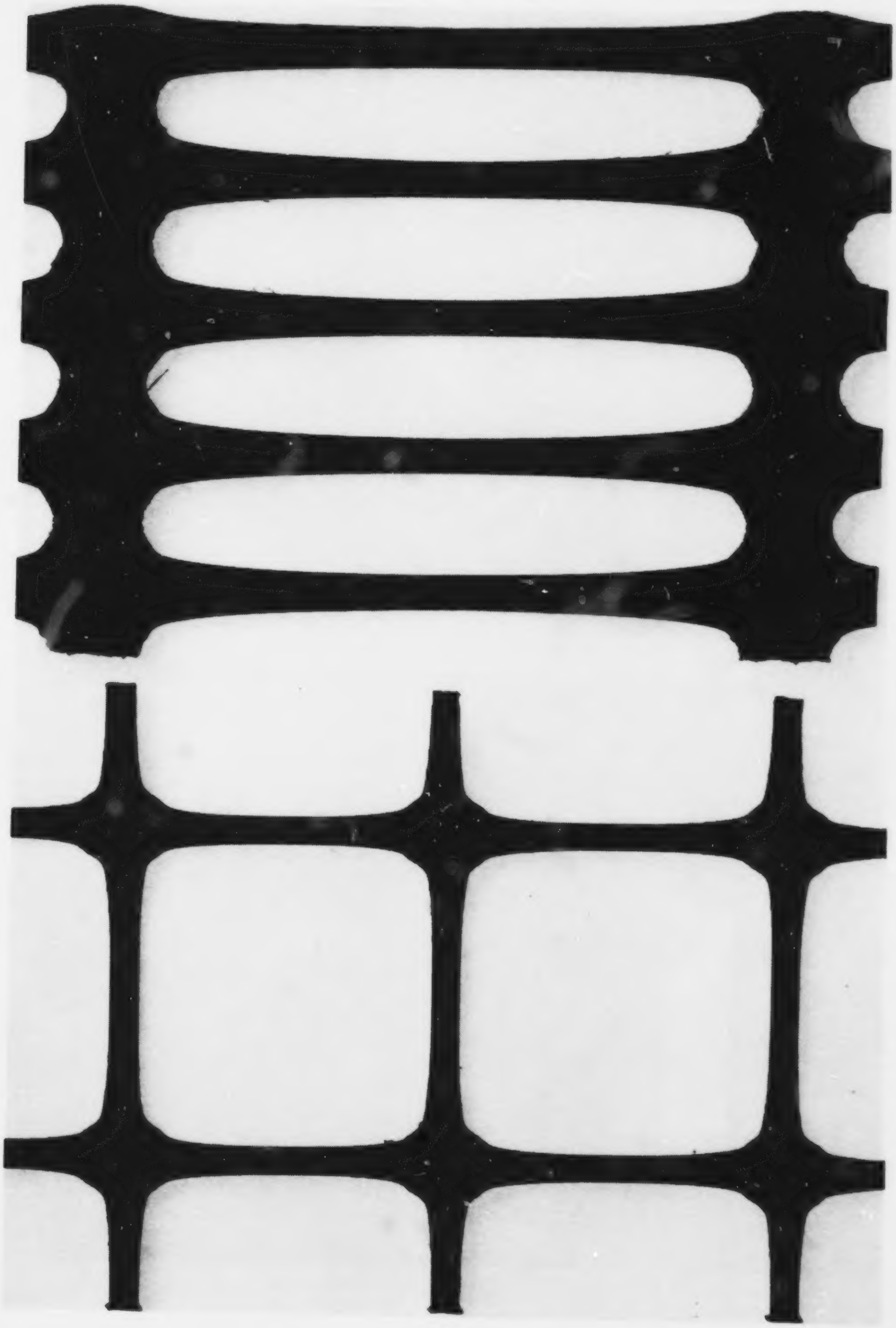
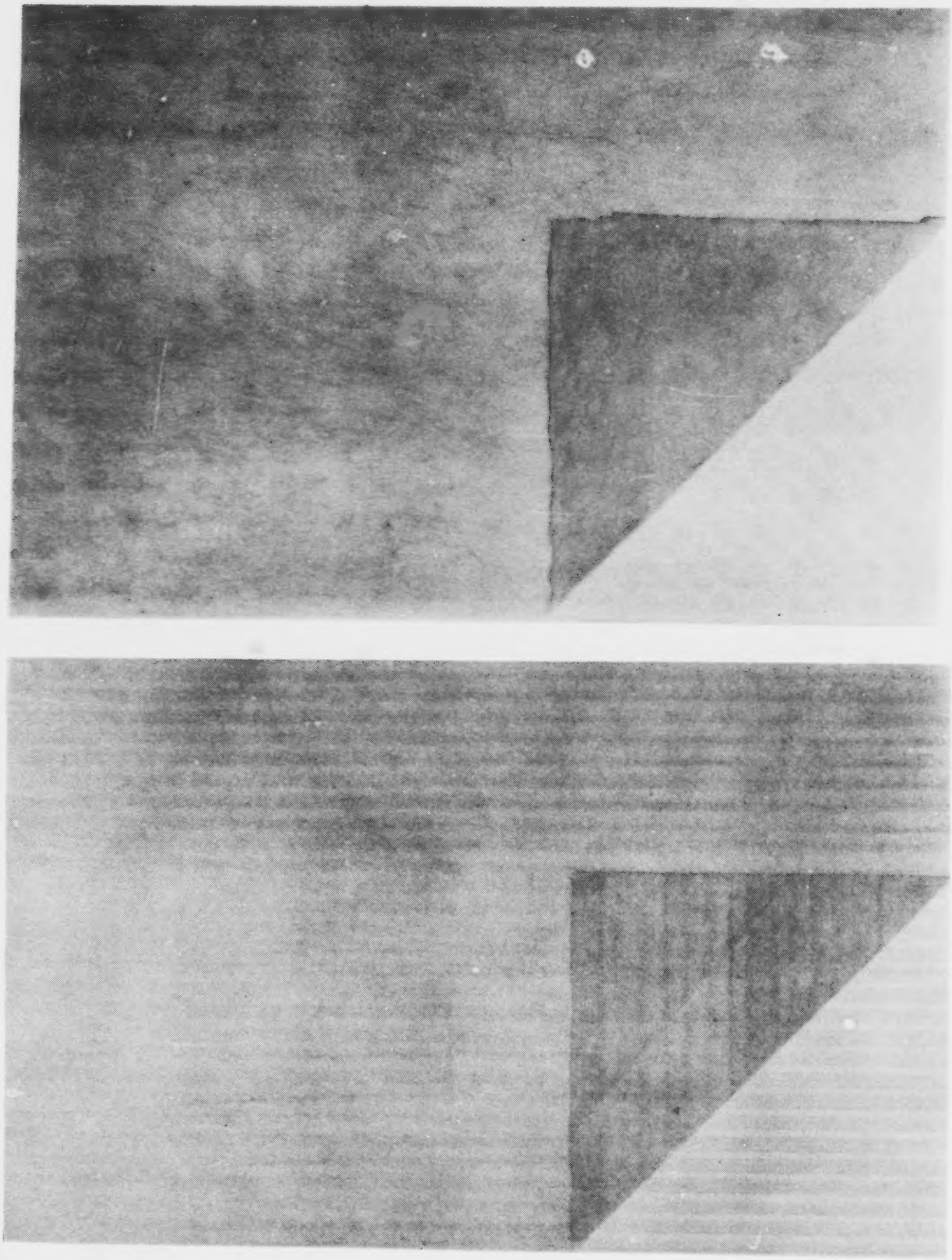


FIGURE 1-9

STRIP DRAINS: ALIDRAIN TYPE (TOP) AND GEODRAIN (BOTTOM)



installation as vertical drains to accelerate consolidation as part of a preload fill technique, the strip drain roll is mounted on the specialized insertion equipment much like a spool of thread on a sewing machine, and the drain is inserted within a mandrel into the soft soil to the required depth. The drain is then cut off 0.3 m (1 ft) or so above the ground surface after the mandrel is withdrawn, and the insertion machine is moved to the next location to repeat the operation. Such a procedure permits economical placement of a large number of drains over an area at close spacing (generally 0.9 to 1.8 m, or 3 to 6 ft, grid on centers). After all drains are in place over the specified construction site area, a layer of pervious soil (sand) is placed around and over the protruding drain ends. The area is then covered with a sufficient thickness of additional random fill to somewhat exceed stresses expected to be imposed by the structure to be built. After consolidation (settlement) of the soft soil is sufficiently complete, the surcharge fill is removed, and select, compacted fill is placed, if required, to bring the site to grade.

1.3.3.3 Drainage Panels

These products constitute any of a number of proprietary products consisting of a grid or mat panel sandwiched between filter fabric (Figure 1-10). They have most commonly been used to provide drainage behind reinforced concrete retaining walls or to lower the ground-water table next to building foundations. The fabrics have also been used in a horizontal orientation beneath athletic playing fields to improve drainage. Most applications require a perforated drain pipe to be installed at the lower edge of the panels to collect and accelerate flow away from the area. The panels are manufactured in a way that allows them to be overlapped to prevent soil infiltration along the edges between panels.

1.3.3.4 Coated Fabrics

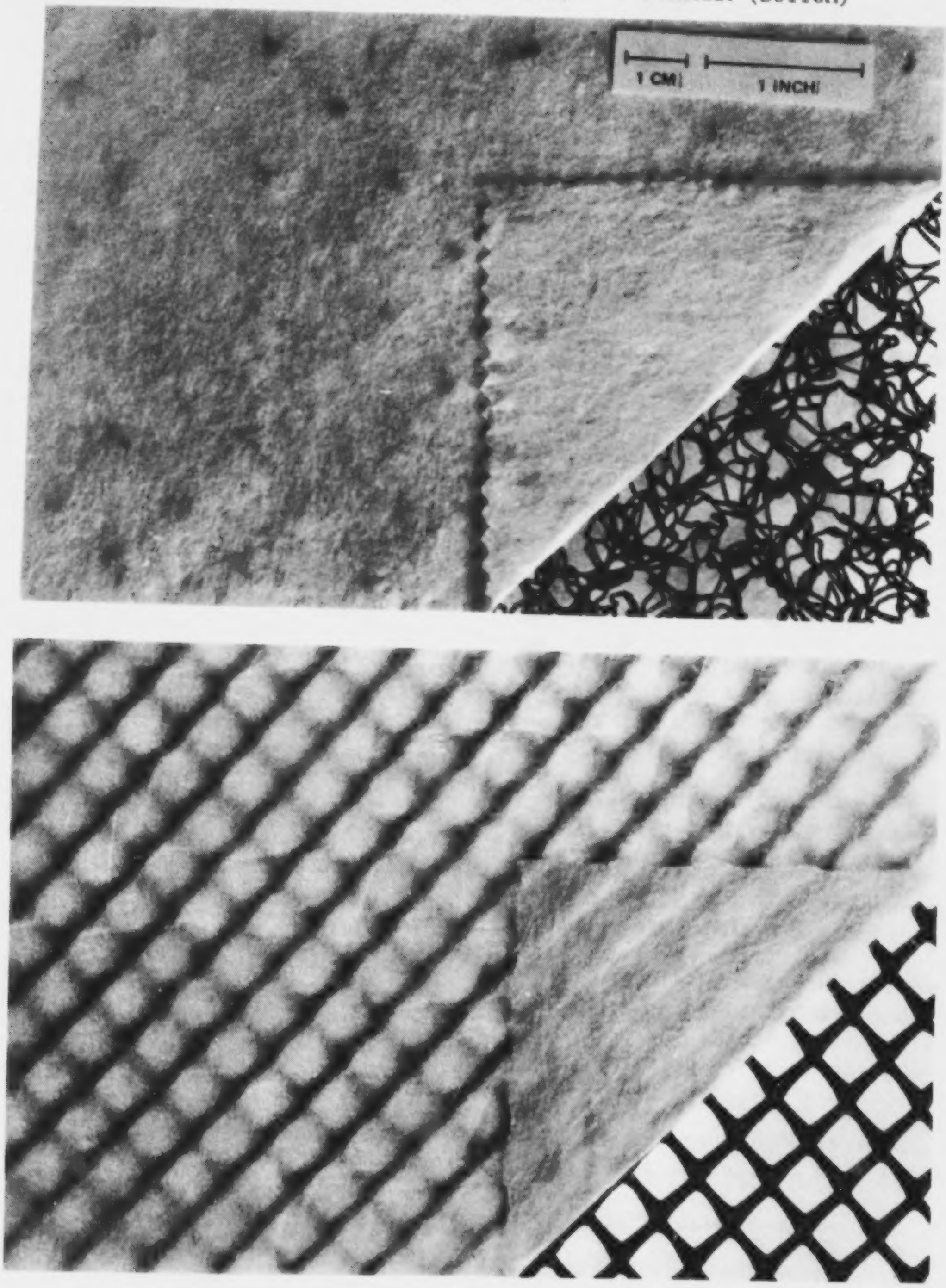
The foregoing discussion has dealt only with products that can be classified as permeable to liquids and gases. Fabrics are, however, used extensively as reinforcement for impermeable synthetic membranes. These membranes are used extensively as liners for water, wastewater, and other liquid/slurry lagoons, and in the capping or covering of solid waste disposal sites. Heretofore their higher cost has discouraged their use in capping operations. Recently on the market, however, are several less expensive products that can be considered as hybrids between fabrics and membranes. These differ from conventional fabric-reinforced membranes in that an impermeable film of either ethylene vinyl acetate or polyethylene is bonded to one side of a nonwoven fabric, partially penetrating the fabric thickness. Because the bonding systems are only partially penetrating and as yet unproven, these materials may not be suitable for liquid containment, but they could function well as water-shedding elements in a cap or cover design. They offer greater strength and puncture resistance than the unreinforced membranes now used most widely.

1.4 Geotextile Functions and Applications

In geotechnical and waste management engineering, geotextiles perform one or more of five functions: filtration, drainage, reinforcement, erosion

FIGURE 1-10

DRAINAGE PANELS: ENKADRAIN (TOP) AND FILTRAM (BOTTOM)



control, and separation. Table 1-2 lists possible applications of geotextiles in hazardous waste landfills, for each of the primary functions.

1.4.1 Filtration

The use of geotextiles as drain filters is probably the most widely known and used application of geotextiles. The geotextile is used to surround a drainage structure to prevent finer soil (or waste) from entering the drain and reducing its flow capacity. In this function, it substitutes for the traditional graded granular sand and gravel filter used in geotechnical engineering. Both the granular filter and the geotextile filter must keep the finer material in place while allowing water, effluent, or gas to pass without buildup of hydrostatic pressure.

Geotextiles are commonly used as filters in leachate collection systems, where they separate the drainage blanket from the overlying waste. They are also often used in ground-water interceptor trenches, where they line the trench to prevent the surrounding soil from piping and infiltrating the drainage material. Geotextile filters have also been used in multilayer waste cover systems, where they are used to surround the cover's drainage layer.

One use of geotextiles as filter that differs somewhat from the uses previously mentioned is in the construction of silt fences. These temporary structures are intended to reduce the amount of soil lost from a construction site and prevent contamination of water courses because of surface erosion from storm runoff. Typical locations of silt fences are the toe of fill slopes, the downhill side of large cut areas, and along ditches and natural drainage areas. The silt fence serves to reduce the velocity of the running water, allowing soil solids to settle out of suspension, and to filter the water as it flows through the openings in the fabric.

1.4.2 Drainage

When used as a drain, a geotextile-related product acts as a conduit for liquids or gases. These products usually substitute for gravel and perforated pipe traditionally used in geotechnical engineering for drainage applications. Thick, needle-punched fabrics, grids, and meshes are used to drain gases from beneath synthetic membrane pond liners. Geotextile-related products can be used in trench drains and blanket drains as a substitute for granular material. Geotextile products are particularly effective on the sloping sides of waste impoundments. If a sand drainage blanket were used as part of a leachate collection system, the steepness of the impoundment sideslope would be limited by the angle of repose of the sand, whereas a geotextile product could be placed on any slope on which a synthetic membrane could be placed.

1.4.3 Reinforcement

Reinforcement is the process of adding mechanical strength by inclusion of the fabric element. Geotextiles can be used in various applications to provide tensile strength to soil, or to add support and tensile strength to a synthetic membrane. Geotextiles are often placed beneath and on top of synthetic membranes to act as a cushioning and load-distribution layer to

TABLE 1-2

FABRIC FUNCTIONS AND POSSIBLE APPLICATIONS IN HAZARDOUS WASTE LANDFILLS

Function	Application
Filtration	• Prevent intrusion of fine particles into the drainage layer of multilayered cover systems while allowing water through from above.
	• Provide filter above drainage blanket in leachate-collection systems.
	• Provide filter layer in ground-water interceptor trenches.
	• Wrap collector pipes.
	• Serve as silt fences.
	• Provide filter layer for structure drains.
	• Serve as observation well screens.
	• Provide filter layer between gas transmission layer and surrounding soil or waste.
Drainage	• Serve as drainage layer in multilayer cover system.
	• Substitute for granular material and drain pipe in ground-water interceptor trenches.
	• Provide drainage layer for structure drains.
	• Serve as transmission layer of leak-detection system.
	• Provide gas vents.
	• Provide drainage layer in leachate collection system.
	• Accelerate consolidation of soft waste.
Reinforcement	• Serve as waste containment dikes on soft soils.

(Continued)

TABLE 1-2 (Continued)

Function	Application
Reinforcement	• Form earth walls to aerate waste-holding areas in restricted spaces.
	• Protect synthetic membranes from puncturing and impact damage and provide support.
	• Use on construction haul roads over soft ground.
	• Capping waste lagoons.
Erosion control	• Protect landfill covers, swales, and ditches from runoff either temporarily until vegetation is established, or in conjunction with additional armoring, for permanent protection.
	• Protect streambank from erosion when landfills are adjacent to lakes and ponds.
	• Wave protection when landfills are adjacent to lakes or ponds.
	• Prevent erosion at culvert outlets and other outlet structures.
Separation	• Use to cap waste lagoons.
	• Use on construction haul roads over soft ground.
	• Beneath drainage layer in leachate collection systems.

that reduces the incidence of puncturing and tearing. Fabrics are used to reinforce the bases of dikes built on soft foundation soils, and they can be used in the construction of retaining walls. Fabric is also used extensively in the construction of haul roads over soft ground. Fabric is placed over the soft ground, and graded aggregate is placed over the fabric. The aggregate distributes the load from the wheels of vehicular traffic, and the fabric prevents the aggregate from spreading and sinking into the soft ground.

1.4.4 Erosion Control

In erosion control, geotextiles protect soil or vegetation against the tractive forces of moving water. Fabrics are most commonly used in ditch linings for erodible fine sands or cohesionless silts. The fabric lines the ditch, and rock or gravel is placed on the fabric to secure it in place, shield the fabric from ultraviolet light, and dissipate the energy of the flowing water. Geotextiles are also used to provide temporary protection against sheet erosion on newly seeded slopes. Fabric designed for the purpose is anchored to the slope after seeding and holds the soil and seed in place until vegetative cover is established. Most products used for this purpose are designed to disintegrate after the vegetation has had time to establish itself, but at least one product is designed to remain in place permanently and provide additional anchorage for plant roots.

1.4.5 Separation

Separation is the process of preventing two dissimilar materials from mixing. The most common application of fabric acting as a separator is in the capping of waste lagoons. The fabric is rolled out or otherwise spread over the surface of the waste and covered with soil. This provides a stable working surface on which to place capping layers of either synthetic membrane or soil. In separation applications, the ability of the fabric to pass water is of secondary importance and may not be necessary at all. In construction of expedient haul roads over soft soil, fabric is placed over the soft subgrade, and gravel or crushed stone is placed on the fabric. In addition to providing a reinforcing function, fabric acts as a separator, preventing the subgrade from intruding into the overlying coarser material.

1.5 Summary

1.5.1 Advantages and Disadvantages of Geotextiles

As illustrated in the foregoing sections, geotextiles can perform many functions in the containment and land disposal of hazardous waste. Whether a fabric is selected to solve a particular environmental/geotechnical problem will require the weighing of a number of factors.

Some of the advantages of fabric use are as follows:

a. A fabric provides tensile strength. In many instances, the properties of fabrics mesh ideally with those of soil to form a composite structure of great effectiveness.

b. Fabric can provide consistent product quality. Material properties can be varied and controlled to a great degree to suit a particular purpose.

c. Fabrics are widely available. They can be supplied to sites in remote areas relatively easily, and they can often substitute for natural materials that are simply not available.

d. In many applications, savings in time and labor costs may justify the use of fabric even when traditional construction materials are available at lower costs.

e. Fabric may make construction possible in areas such as soft ground areas where construction would be nearly impossible otherwise.

Some of the limitations of fabrics are as follows:

a. Because the use of fabrics is relatively new and unfamiliar to many practicing engineers and contractors, knowledge of proper design and installation practices may be lacking, leading to improper installation and failure to perform the intended function.

b. When used for filtration, separation, and erosion control, fabrics lack the self-healing qualities characteristic of granular materials traditionally used in these applications. Extra strength may be advisable to allow for the potential for damage during installation and environmental uncertainties after installation.

c. The functional lifetime of fabrics is not known in the geotechnical environment, and it is particularly unknown in the potentially hostile chemical environment of a hazardous waste landfill.

1.5.2 Costs

Table 1-3 provides typical 1983 cost ranges for engineering fabrics and related products. Specific prices for a given application may be obtained from the suppliers listed in Appendix A. The cost of fabric for a specific project depends on current supply and demand and on such factors as the prestige or significance of the particular project. Often it is often less costly for the project as a whole to select a fabric having a higher initial cost if the fabric has properties that expedite construction, reduce labor costs, and reduce the chances of damage that must be repaired later.

TABLE 1-3

TYPICAL COSTS OF ENGINEERING FABRICS AND RELATED PRODUCTS

Type of Product	Material	Properties	Price Range[a]	
			Less than 500 yd^2	More than 50,000 yd^2
Woven monofilament for filtration or reinforcement	Polypropylene	EOS 40 to 100 available[b] Tensile strength, 1,334 N (300 lb)[c]	$1.40 - 1.03	$1.08 - 0.72
Woven monofilament for reinforcement	Polypropylene	Tensile strength, 1,334 N (300 lb)[c]	1.40 - 1.02	1.08 - 0.72
Woven slit-film for fence	Polypropylene	Tensile strength, 445 N (100 lb)[c]	0.60	0.42
Woven slit-film for separation and reinforcement	Polypropylene	Tensile strength, 890 N (200 lb)[c]	0.70 - 0.55	0.49 - 0.41
		Tensile strength, 1,334 N (500 lb)[c]	0.90	0.63
Woven multifilament for reinforcement	Polypropylene	Tensile strength, 2,224 N (500 lb)[c]	1.70	1.22

(Continued)

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[a] Price survey made in 1983. Prices vary according to market demand and significance of job. Price per square yard except as noted. For conversion to metric, 1 yd^2 = 0.836 m^2; 500 yd^2 = 418 m^2; 50,000 yd^2 = 41,800 m^2; 1.196 × $/$yd^2$ = $/$m^2$.

[b] EOS: Equivalent Opening Size as given in U. S. Army Corps of Engineers Guide Specification CW-02215.

[c] ASTM D 1682 Grab Test; strength for both principal directions averaged unless otherwise noted.

TABLE 1-3 (Continued)

Type of Product	Material	Properties	Price Range	
			Less than 500 yd²	More than 50,000 yd²
Woven multifilament for unidirectional reinforcement	Polypropylene	Tensile strength, 4,893 N (1,100 lb)[c] (one direction only)	\$3.75 - 3.39	\$2.63 - 2.43
Nonwoven heat-bonded for filtration and separation	Polypropylene	113-179 g (4-6 oz) EOS 70 up	1.01 - 0.69	1.00 - 0.60
Nonwoven needled for filtration and reinforcement	Polypropylene	128 g (4.5 oz)	0.73 - 0.60	0.55 - 0.47
		EOS variable		
		170 g (60 oz)	0.88	0.69
		generally 70		
		227 g (8 oz) up	1.22 - 0.87	1.01 - 0.72
		283 g (10 oz)	1.30	--
Nonwoven needled for filtration and reinforcement	Polypropylene	340 g (12 oz)	\$1.62 - 1.22	\$1.33 - 1.02
		454 g (16 oz)	2.39 - 2.05	1.97
	Polyester	113 - 128 g (4-4.5 oz)	0.61	0.59
		170 g (6 oz)	0.90 - 0.80	0.78 - 0.63
		227 g (8 oz)	1.71 - 1.10	1.12 - 0.71
		283 (10 oz)	1.40 - 1.30	1.38 - 0.91
		340 g (12 oz)	0.60	1.12
		454 g (16 oz)	2.38 - 1.90	2.26 - 1.33
		567 g (20 oz)	2.25	1.58
Combination nonwoven needled scrim for filtration	Polyester w/ polyester scrim	EOS - 100+	2.80 to 4.00 and up depending on other treatments and weights	

(Continued)

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[c] ASTM D 1682 Grab Test; strength for both principal directions averaged unless otherwise noted.

TABLE 1-3 (Continued)

Type of Product	Material	Properties	Price Range	
			Less than 500 yd^2	More than 50,000 yd^2
Drainage panels	Varies from product to product. Polyethylene core with thin nonwoven fabric on both sides. EOS of panels can vary as well as drainage capacity and load capacity.		\$1.38 - 0.69 per ft^2	\$1.12 - 0.56 per ft^2
Special product - permanent surface erosion protection	Nylon	Thick open-mesh mat, 8.9 - 17.8 mm (0.35 in. - 0.7 in.) thick	6.79 - 4.04	5.50 - 3.54
Special product- temporary erosion protection; seedbed protection	Polypropylene and paper	Open knit yarn interlaced with paper; product degrades after exposure	0.58	0.49
Reinforcement grid	High-density polyethylene	Tensile strength 78.8 kN/m (450 lb/in.)[d]	5.42	4.74
Separation/reinforcement grid	Polypropylene	Tensile strength, 16.1 kN/m (92 lb/in.)[d]	1.17	1.00
		Tensile strength, 24.9 kN/m (142 lb/in.)[d]	1.91	1.66
Drainage grid	Medium-density polyethylene	Thickness: 6.4 mm (0.25 in.)	2.96	2.58
Gabion grid	High-density polyethylene	Tensile strength, 14.9 kN/m (85 lb/in.)[d]	2.41	2.09

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[d] Uniaxial strip-type test; strength for stronger principal direction only.

2.0 EVALUATION OF FABRIC PROPERTIES

2.1 General Physical Properties

Geotextiles were developed from conventional textile technology and much of the way of thinking of geotextiles and evaluating them, particularly by manufacturers and marketers in the early days of geotextile use, came from textile industry practice. Such general physical properties as fiber composition, fabric construction, weight per unit area, thickness, and fiber diameter are still useful in describing fabrics and for identification purposes. Also, some of the general physical properties of fabrics can have very practical uses. For example, the width and length of fabric rolls can be of practical importance to a contractor in judging how best to handle the fabric for installation. Also, knowledge of the specific gravity of a fiber making up a fabric can be useful because in some applications the fabric must be able to sink in water and in other applications the fabric must float. The specific gravity of the fiber tells the prospective user which the fabric is likely to do. Water absorption can also be important since a fabric that readily absorbs water can become difficult to work when placed on wet ground. Whereas a fabric that is hydrophobic is much more easily worked in these circumstances. Though the information discussed above is useful for evaluating fabrics for many engineering applications, the more significant properties from an engineering standpoint are the mechanical, hydraulic, and environmental endurance properties discussed in the following sections.

2.2 Mechanical Properties

The mechanical properties of engineering fabrics include tensile strength, tensile stress-strain relationship (or modulus), puncture and burst resistance, penetration resistance, creep resistance, abrasion resistance, tear resistance, flexibility, soil-fabric sliding resistance, and fatigue resistance. These qualities are most important to reinforcement applications of geotextiles and to the survivability of the fabric during installation. Ease of installation is also affected by such qualities as flexibility.

2.2.1 Tensile Strength

The first comprehensive effort to evaluate fabrics for engineering purposes was made by Calhoun and reported in 1972. In his studies, he adapted test methods already in use in the textile industry. For tensile strength this was the test described in ASTM D 1682.[a] Three methods are described in this ASTM standard: the cut strip test, the ravelled strip test, and the grab test. The test configurations for the ravelled strip and the grab tensile test are illustrated in Figure 2-1. All of the these tests are uniaxial tensile tests in which stress is applied to the fabric in one direction only.

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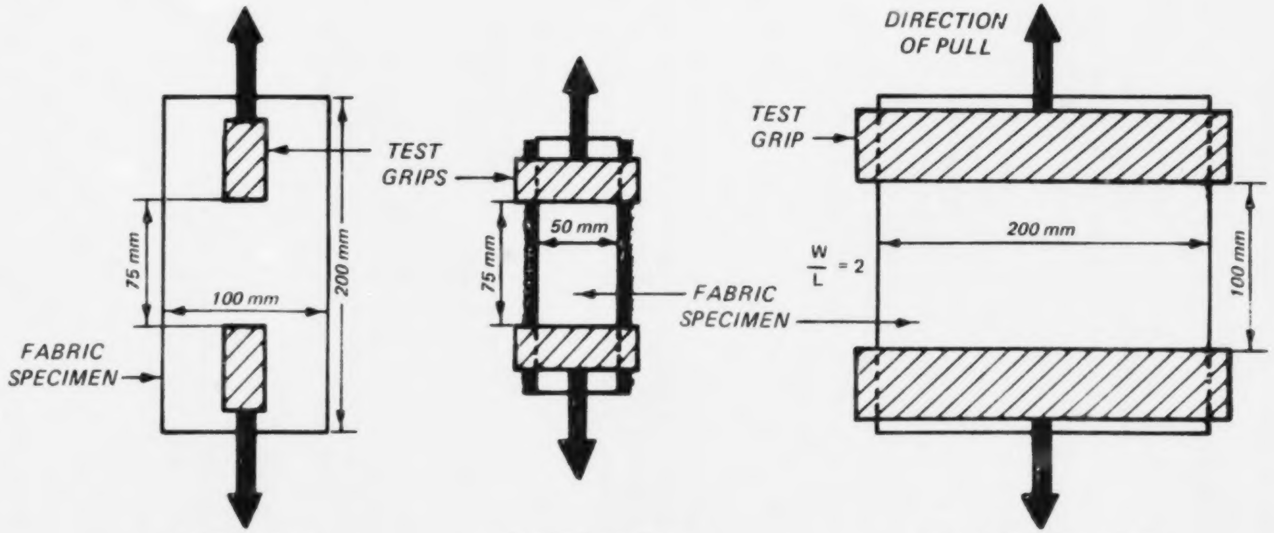
[a] See Appendix B for a list of all ASTM test methods mentioned in this handbook.

FIGURE 2-1

METHODS OF DETERMINING UNIAXIAL TENSILE STRENGTH OF GEOTEXTILES


DIRECTION
OF PULL
TEST
GRIPS
FABRIC
SPECIMEN
75 mm
100 mm
200 mm
50 mm
75 mm
FABRIC
SPECIMEN
TEST
GRIP
W/L = 2
200 mm
100 mm

ASTM GRAB TENSILE TEST

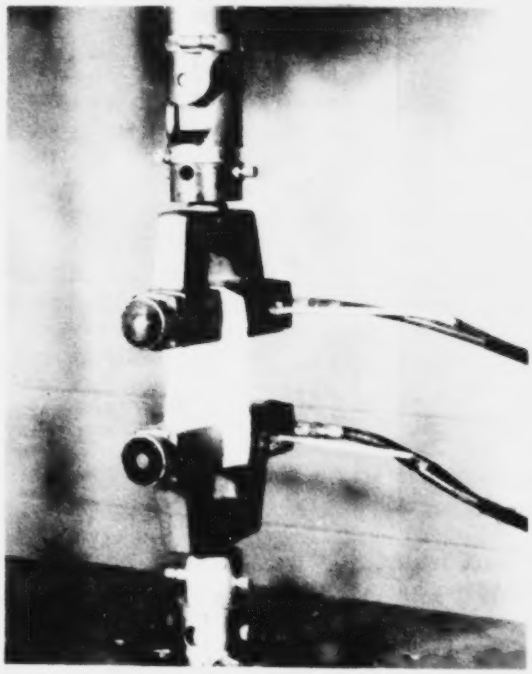
ASTM STRIP TENSILE TEST (2-INCH RAVELED STRIP ILLUSTRATED)

ASTM PROPOSED WIDE - WIDTH TENSILE TEST, W/L = 2

These tests were developed for rapid quality control purposes in the textile industry and have several potential disadvantages when applied to geotextiles. The method used by Calhoun and cited in most strength specifications for geotextiles is the grab test method. The test uses a 100- by 200-mm (4- by 8-in.) fabric specimen that is pulled by a set of grips spaced 75 mm (3 in.) apart (see Figure 2-2). Grips 25-mm (1 in.) square have been used most commonly in the past, although 25-mm by 50-mm (1-in. by 2-in.) grips are also allowed by the method and are now the preferred size. The grab test method is a valuable test because of its simplicity and because it simulates the type of localized stressing that often occurs in actual installations. Nevertheless, the test has several limitations. First, it is impossible to evaluate the strength of the fabric that is directly between the grips because of the strength contribution of the surrounding fabric. When a fabric is used in reinforcement applications where the strength per unit width of the fabric must be known, this method tends to overstate the fabric strength. The second limitation of the test is that while it evaluates the strength in uniaxial tension, in most applications a fabric is actually undergoing either biaxial (plane-strain) or triaxial stressing. This is an important limitation, since the strength--and especially the stress-strain properties of nonwoven fabrics and to a lesser degree woven fabrics--differ radically depending on whether the fabric is undergoing one-, two-, or three-dimensional stressing. For example, in most cases when a fabric is placed in tension in a reinforcing application, it is surrounded by the confining pressure of soil creating interfiber friction that acts to inhibit the movement of fibers relative to each other. There have been several attempts to simulate more closely the

FIGURE 2-2

THE GRAB TENSILE TEST



stress state of fabrics in the field. Some attempts have been restricted to the biaxial stress state where the fabric is pulled simultaneously in two directions or where the lateral straining of the fabric has been prevented or minimized. Most of the test methods that have been tried have proved to be too complex for practical application (Sissons, 1977; Viergever et al., 1977). The most ambitious attempt to simulate actual field tensile stress conditions in the laboratory has been by McGown and Andrawes (1982). In this test, fabric specimens are tested in tension while actually confined in soil at various pressures (see Figure 2-3). The results of tests performed in this apparatus have demonstrated that the stress-strain properties of fabrics confined in soil can be radically different from the properties of fabrics tested in an unconfined state.

An attempt to develop a compromise test that would provide more realistic strength and modulus properties than those provided by the conventional grab and strip tensile tests has led to the development of the so-called wide-width tensile test. This is a uniaxial strip tensile test in which the fabric specimen is much wider than the distance between the gripping jaws. This configuration tends to minimize the effect of the lateral contraction of the outer portion of the fabric specimen on the strength and modulus values of the fabric. Work done by the French Geotextiles Committee has led to their specifying a ratio of 1 to 5 for the ratio of distance between the grips to the width of the specimen (LeFlaive et al. 1982). ASTM is currently developing a wide-width tensile test having a 1 to 2 ratio gage length (the distance between the grips) to specimen-width. This has been accepted as a reasonable compromise, as research by Shrestha and Bell (1982a) and McGown et al. (1982) has shown that a gage-length-to-width ratio of 1 to 2 provides reasonable results for both woven and nonwoven fabrics.

A third limitation of standard tensile testing methods is that it is designed for quality control purposes where speed of test results is important, thus the rate of testing specified is much too high to simulate the rate of straining in geotechnical applications. Several investigations (Shrestha and Bell, 1982a; Haliburton et al., 1978) have experimented with a reduced test rate that is from the commonly used 305 mm (12 in./min) which is equal to 400 percent strain/min to a rate of 0.5 to 10 percent strain/min. A compromise testing rate that considers both testing time and cost, and the cost and rate of straining typical of geotechnical field situations has resulted in a recommended rate of 10 percent/min for the proposed ASTM standard wide-width tensile test.

2.2.2 Tensile Modulus

Tensile strength alone does not tell the whole story about the strength behavior of a fabric under load. Of significant importance is the tensile modulus or the way in which the fabric resists straining. Figure 2-4 gives typical stress-strain curves for engineering fabrics in uniaxial tension. As can be seen from the figure, different fabric constructions lead to vastly different stress-strain properties. No one stress-strain curve shape is desirable for all applications. For reinforcement applications, generally a curve in which the stress builds up rapidly with very little strain is most desirable. In erosion control or drainage and filtration applications,

FIGURE 2-3

LAYOUT OF TEST APPARATUS FOR PERFORMING LOAD-EXTENSION TESTS ON FABRIC IN CONFINEMENT (McGown and Andrawes, 1982)

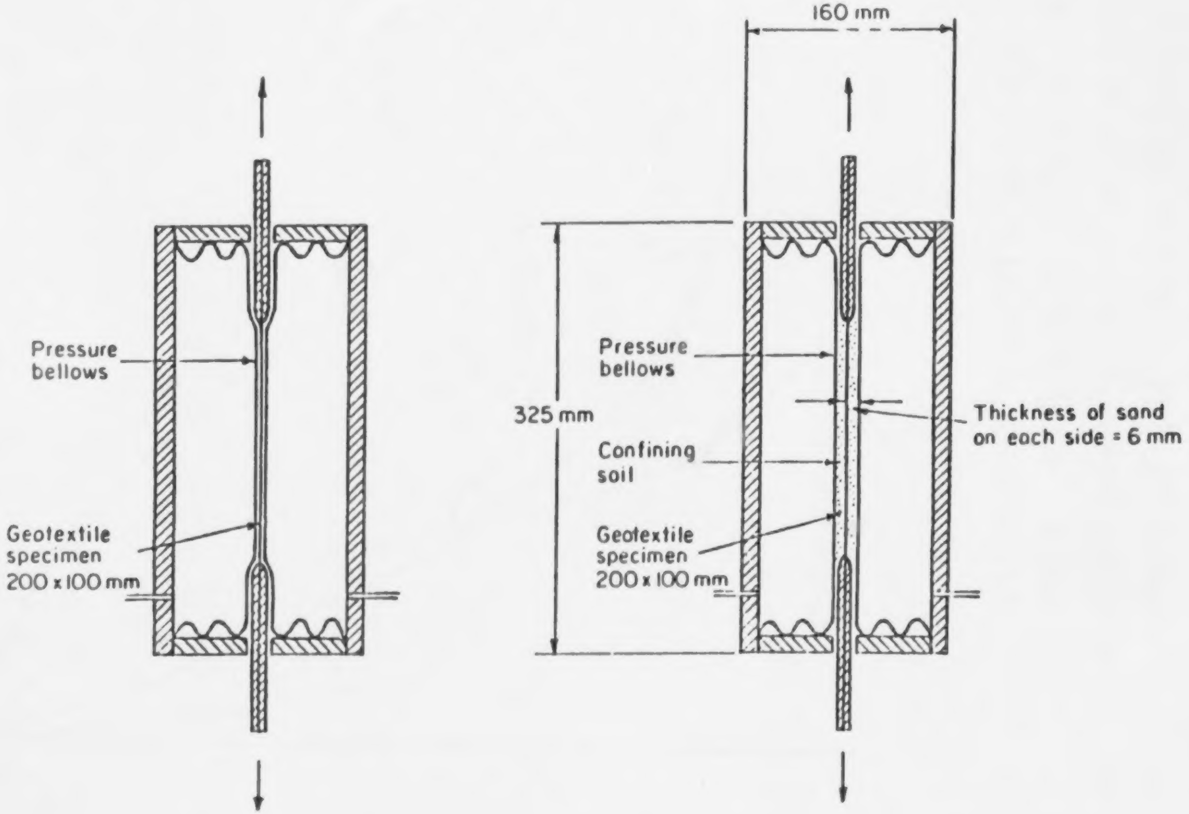
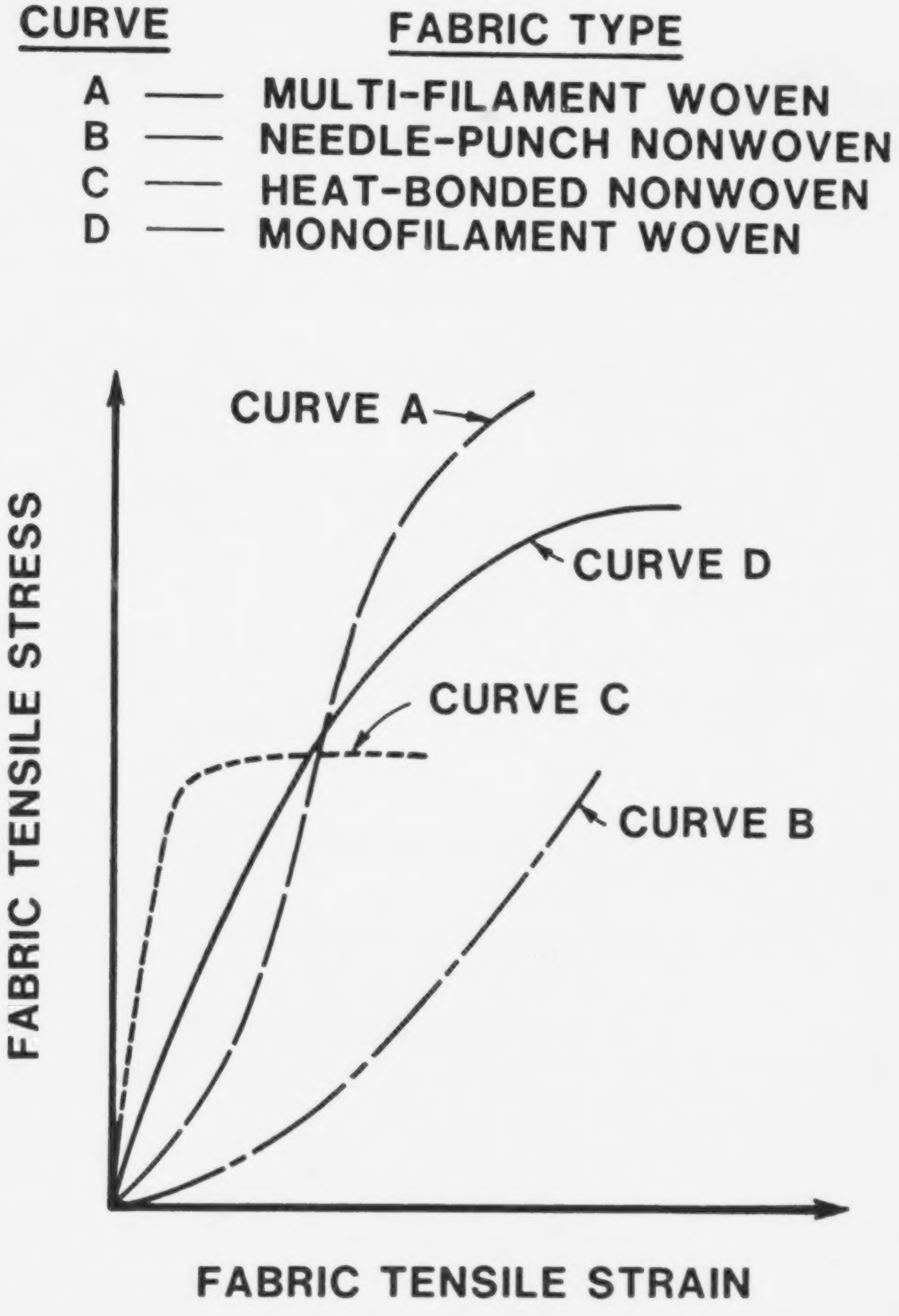

Pressure bellows
Geotextile specimen 200 x 100 mm
160 mm
325 mm
Pressure bellows
Confining soil
Geotextile specimen 200 x 100 mm
Thickness of sand on each side = 6 mm

FIGURE 2-4

TYPICAL STRESS-STRAIN CURVES FOR GEOTEXTILES IN UNIAXIAL TENSION
(Haliburton et al., 1981)



however, where the fabric may be struck by rocks or have to conform to irregular surfaces, a stress-strain curve such as illustrated by curve B would be much more desirable. Figure 2-5 illustrates three methods of determining the tensile modulus of engineering fabrics from stress-strain data. The figure illustrates how the modulus will vary depending on the method used for determining it. For reinforcement applications, a secant modulus at a strain of about 10 percent has been used commonly (Haliburton et al., 1981). Just as for tensile strength, the rate of testing is important in evaluating the modulus of a fabric.

2.2.3 Puncture and Burst Resistance

Bell et al. (1980) point out that there are several mechanisms that can cause localized fabric failure, and resistance to these mechanisms can be classified as:

a. Burst resistance: The resistance of fabric to rupture from pressure applied normal to the plane of the fabric (bursting results from fabric tensile failure). This type of failure is likely to occur, for example, where a fabric supports an impermeable membrane across a crack or depression in the soil or rigid substratum.

b. Puncture resistance: The resistance of a fabric to failure from a load applied over a relatively small area by a blunt object with failure resulting from fiber tensile failure. This type of failure is closely related to bursting failure in that the basic tensile strength and elongation characteristics of the fabric are the major determining factors in resistance.

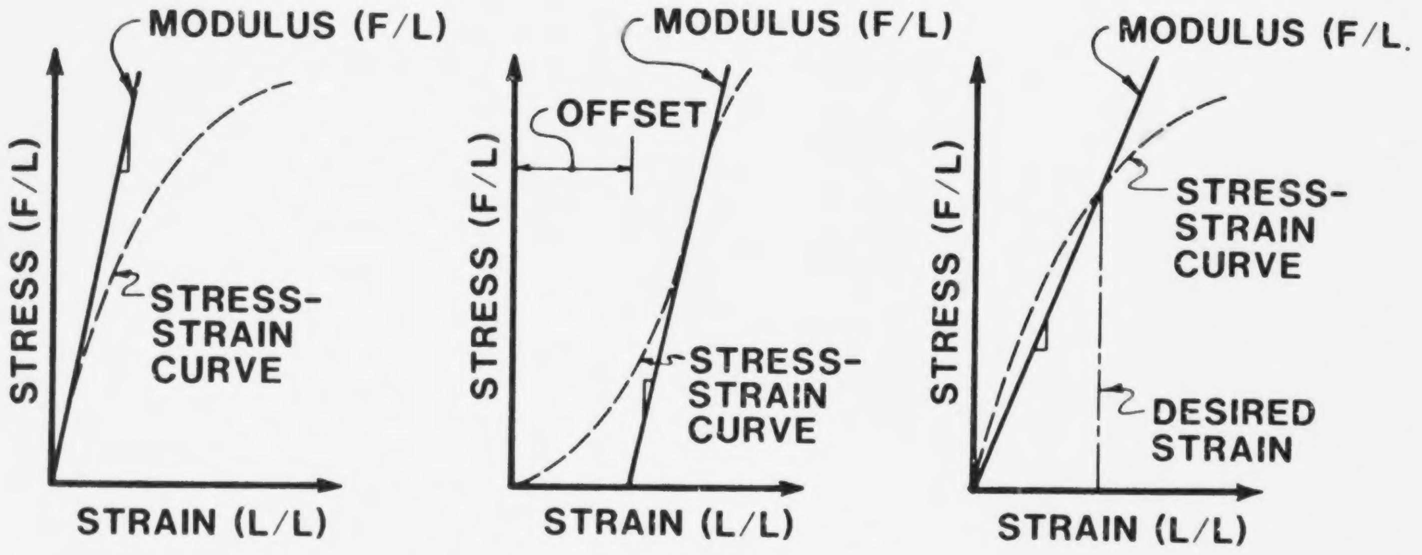
c. Penetration resistance: The resistance of the fabric to penetration by a sharp, pointed object with initial penetration resulting in fiber separation and further penetration causing a tearing of the fabric.

d. Cutting resistance: The resistance of the fabric or fabric fiber to cutting (actually shear failure) when struck between two hard objects. An example of this type of failure occurs when fabric is resting on a rock and another rock is dropped on the fabric.

The tests for burst and puncture resistance used in the United States are described in ASTM D 3786, "Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics: Diaphram Bursting Strength Tester Method," and D 3787 "Bursting Strength of Knitted Goods: Constant-Rate-of-Traverse (CRT), Ball Burst Test." The former method applies an increasing hydrostatic pressure against a fabric held in a 32-mm (1-1/4-in.) inside diameter ring clamp, and the pressure required to fail the specimen is reported as the bursting pressure in kPa or lb/in.^{2}. The latter method uses a ring clamp having a 44-mm (1-3/4-in.) inside diameter. The unmodified test method specifies that a 25-mm (1-in.) diameter polished steel ball be pushed against the specimen until a burst is produced. Calhoun (1972) modified this procedure by

FIGURE 2-5

METHODS FOR DETERMINING TENSILE MODULUS OF GEOTEXTILES FROM STRESS-STRAIN DATA
(Haliburton et al., 1981)


MODULUS (F/L)
STRESS (F/L)
STRESS-
STRAIN
CURVE
STRAIN (L/L)
MODULUS (F/L)
OFFSET
STRESS (F/L)
STRESS-
STRAIN
CURVE
STRAIN (L/L)
MODULUS (F/L.
STRESS (F/L)
STRESS-
STRAIN
CURVE
DESIRED
STRAIN
STRAIN (L/L)

A. INITIAL TANGENT MODULUS

B. OFFSET TANGENT MODULUS

C. SECANT MODULUS AT DESIRED STRAIN

replacing the 25-mm (1.0-in.) diameter ball with an 8-mm (5/16-in.) diameter rod that was pushed through the fabric specimen. The U.S. Army Corps of Engineers has modified this test further by incorporating a hemispherical tip on the rod (Department of the Army, 1977).

2.2.4 Tear Resistance

Once a break has formed in a fabric, tear resistance is the measure of the force required to propagate the break. From field observation, it can be concluded that the tear resistance of a fabric is, for most applications, more important than puncture resistance. Two types of tear tests are currently available for evaluating fabrics--the tongue tear test described in ASTM D 2262 and the trapezoidal tear test described as one of the test procedures in ASTM D 1117. The trapezoidal tear test is currently being considered by ASTM Committee D35 on Geotextiles for adoption as the method of evaluating the tearing resistance of geotextiles. The name of the method comes from the shape of the specimen used in the test. The specimen is trimmed in the shape of a trapezoid with a cut made in the center of the shortest side. The specimen is then clamped in a testing machine and the force required to propagate the cut is reported as the tearing strength. Figure 2-6 shows a test specimen about to be tested, and Figure 2-7 shows the response of the specimen during the test.

FIGURE 2-6

THE TRAPEZOIDAL TEAR TEST BEFORE START OF TEST
WITH SPECIMEN IN CLAMPS

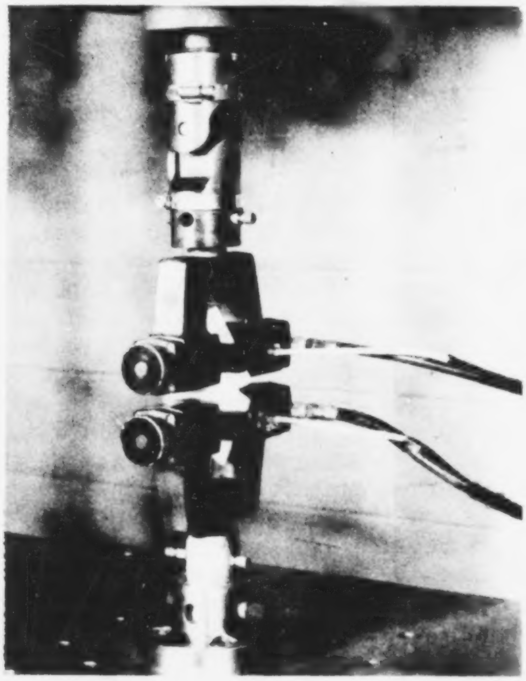
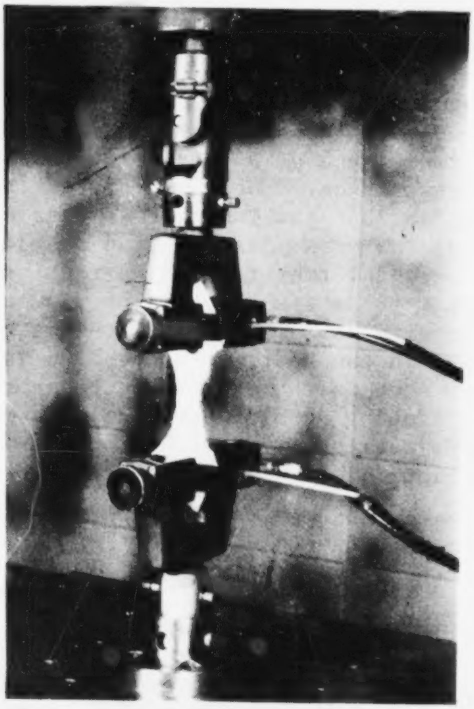


FIGURE 2-7

THE TRAPEZOIDAL TEAR TEST WITH SPECIMEN IN PROCESS OF BEING TORN



2.2.5 Creep Resistance

Creep resistance is an important quality for applications where a fabric must withstand loads for very long periods of time. Research indicates (Allen et al., 1982) that in general, polypropylenes show more creep susceptibility than polyesters, and McGown et al. (1982) has shown that fabrics, when confined in soil, have less creep susceptibility than when tested in isolation. However, all fabrics will creep when subjected to a high enough stress level. Creep testing is used to establish a safe level of stress for the particular application. As yet, there is no standardized test for evaluating the creep susceptibility of fabrics. However, a tensile test in which a constant load was placed on the fabric and the amount of deformation measured over time was used to evaluate fabrics for the reinforcement of the foundation of an embankment at Pinto Pass, Alabama (Haliburton et al., 1978). In this series of tests, a 25-mm (1-in.) wide strip of woven fabric was loaded with dead weights; a dial gage was used to measure the amount of deformation that took place with time. Shrestha and Bell (1982b) performed similar shorter term tests in which they used a wide-width-type tensile apparatus to apply load to the specimen.

2.2.6 Abrasion Resistance

Abrasion resistance is the ability of a fabric to resist wear by friction. Abrasion resistance is a necessary quality in slope protection applications where wave wash or water currents may cause repeated movements of stone or block protection elements against a fabric. Abrasion resistance is of major importance in railroad track rehabilitation where fabric is used to separate ballast from the underlying subgrade and provide drainage for the ballast. The only standardized test for abrasion resistance used to date is ASTM D 3884, Abrasion Resistance of Textile Fabrics (Rotary Platform, Double Head Method), formerly denoted as D 1175. The test consists of a fabric specimen being rotated on a platform while a pair of abrasive wheels roll in a circular track over the specimen. The rate of abrasion varies according to the type of abrasive wheel used, the number of revolutions to which the specimen is subjected, and the weight applied to each wheel. In the typical test, rubber-based abrasive wheels are used, and the specimen is rotated for 1000 revolutions with a 1-kg (2.2-lb) load applied to each of the two wheels. If the fabric specimen is intact after being abraded, a cut strip tensile test specimen is prepared from the abraded fabric and the residual breaking strength is determined. This test was developed by the textile industry to evaluate apparel fabrics and several investigators claim that it does not correlate well with actual fabric performance, at least not in railroad applications. Presently, no other standardized tests exist for evaluating the abrasion resistance of geotextiles, and the method continues to be used where abrasion resistance must be evaluated.

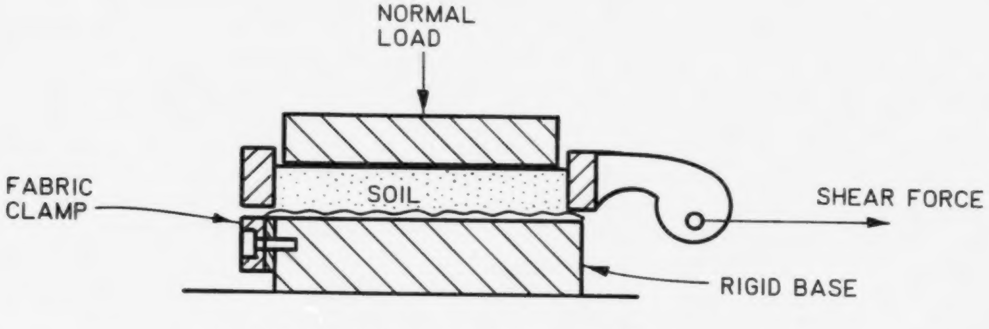
2.2.7 Soil-Fabric Friction

The frictional resistance between soil and fabric is of vital importance in virtually all reinforcement applications. Soil-fabric friction usually provides the sole means by which tensile forces in fabric are transferred to the soil. There are three types of tests for evaluating the coefficient of friction between soil and fabric, as shown in Figure 2-8. The device shown in Figure 2-8a is the simplest and provides valid values for the friction between granular, free-draining soil and fabrics. The device shown in Figure 2-8b differs from that shown in Figure 2-8a in that soil is present on both sides of the fabric. When evaluating the friction between fabric and cohesive soils or soils of low permeability, it may be desirable to use the latter apparatus as the presence of soil on both sides of the fabric more closely simulates the restricted drainage that may exist in the actual field installation.

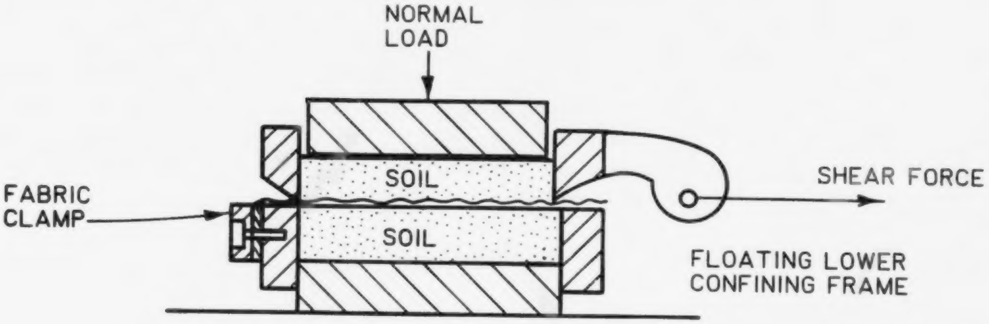
The pullout test shown in Figure 2-8c is the only appropriate way of evaluating the frictional interaction between reinforcement materials such as grids where soil is present in the spaces between the reinforcement members. A direct shear-type test applied to this type of material would measure the shear resistance of the soil present in the spaces between the reinforcement elements without indicating how well the reinforcement was anchored in the soil. As yet, no standardized procedures exist for evaluating soil-fabric friction and pullout resistance.

FIGURE 2-8

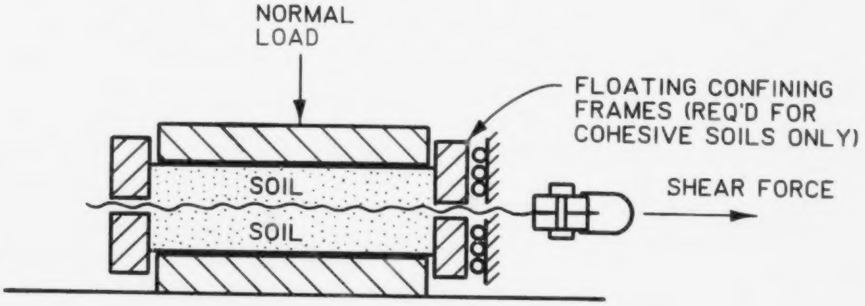
APPARATUSES FOR DETERMINING THE COEFFICIENT OF FRICTION AND PULLOUT RESISTANCE OF FABRICS AND GRIDS


NORMAL
LOAD
FABRIC
CLAMP
SOIL
SHEAR FORCE
RIGID BASE

(a) DIRECT SHEAR TEST SOIL-FABRIC


NORMAL
LOAD
FABRIC
CLAMP
SOIL
SOIL
SHEAR FORCE
FLOATING LOWER
CONFINING FRAME

(b) DIRECT SHEAR TEST-SOIL-FABRIC-SOIL


NORMAL
LOAD
FLOATING CONFINING
FRAMES (REQ'D FOR
COHESIVE SOILS ONLY)
SOIL
SOIL
SHEAR FORCE

(c) PULLOUT TEST

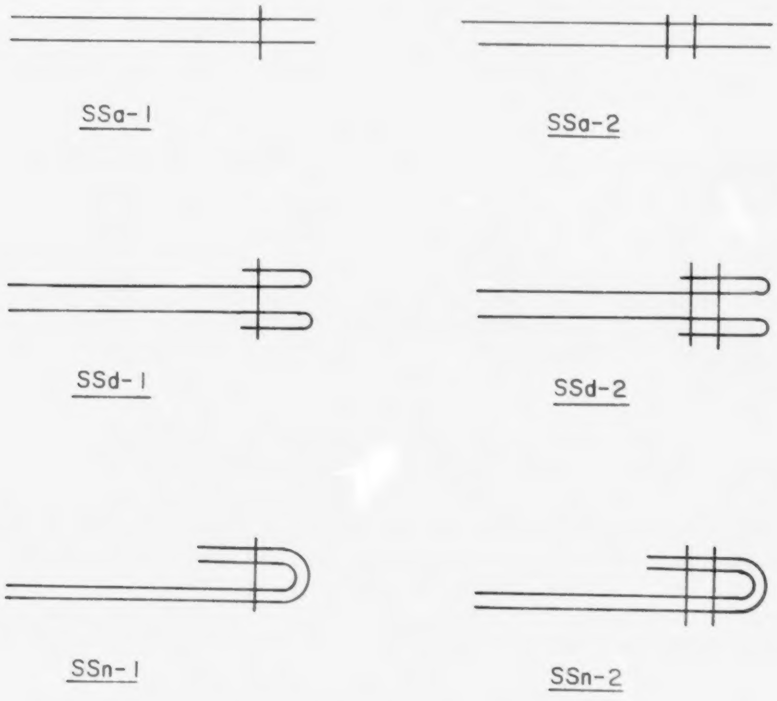
In addition to soil-fabric friction, fabric-fabric and fabric-membrane frictions may be of interest in certain special situations. The same principles illustrated in Figure 2-8 can be applied to evaluate these properties.

2.2.8 Seam Strength

Fabric panels can be joined by overlapping, stapling, heat welding, or sewing. Simple overlapping and staking or nailing to the underlying soil may be all that is necessary where the primary purpose is to hold the fabric in place during installation. However, where the seam between two fabric sheets must withstand tensile stress or where the security of the seam is of prime importance, sewing has proved to be the most reliable method of joining fabric panels. Stronger and more durable seams can usually be produced in a manufacturing or fabricating plant than can be produced in the field. The types of sewn seams that can be produced in the field by portable sewing machines at present are limited to those shown in Figure 2-9. The designations of the seams correspond to the designations in Federal Standard 751a. Provided the fabric is selvedged, the double-sewn seam SSa-2 is the preferred method of seaming. However, where the edges of the fabric are subject to unraveling, SSd or SSn seams are preferred. Currently marketed, the portable sewing machines that can be used to sew seams in geotextiles were originally designed

FIGURE 2-9

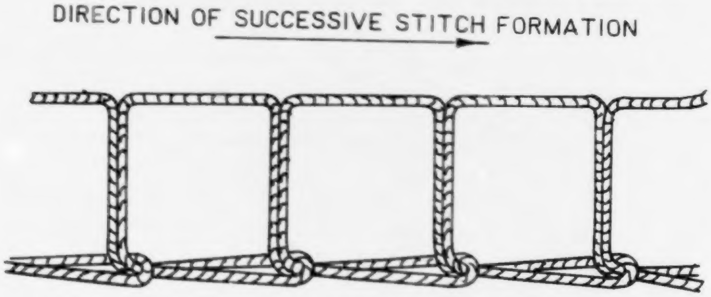
SEAM TYPES USED IN FIELD SEAMING GEOTEXTILES



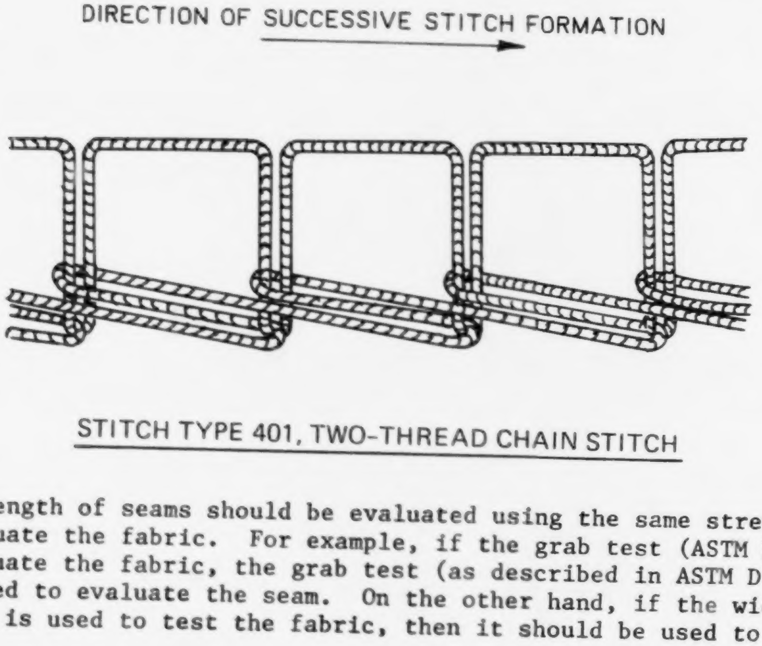
as bag closing machines. These machines produce either a single- or double-thread chain stitch as shown in Figure 2-10. Both of these stitches are subject to unraveling, but the single-thread stitch is much more susceptible and must be tied off at the end of each stitching. Two rows of stitches are preferred wherever possible for all field seaming.

FIGURE 2-10

STITCH TYPES USED IN FIELD SEAMING OF GEOTEXTILES



STITCH TYPE 101, ONE-THREAD CHAIN STITCH



STITCH TYPE 401, TWO-THREAD CHAIN STITCH

The strength of seams should be evaluated using the same strength test used to evaluate the fabric. For example, if the grab test (ASTM D 1682) is used to evaluate the fabric, the grab test (as described in ASTM D 1683) should be used to evaluate the seam. On the other hand, if the wide-width tensile test is used to test the fabric, then it should be used to evaluate the seam.

Seam strength requirements have often been specified as a percentage of the strength of the fabric. In most cases however, the seam strength requirement should be specified to be the same as the fabric strength requirement. Thus if a 334 N grab strength is required of the fabric, a 334 N grab strength should be required of the seam. When using any test procedure, care must be taken to assure that the seam does not fail by unraveling rather than breaking of the fabric or threads.

2.2.9 Flexibility

Flexibility is the property of a fabric that enables it to conform to irregular surfaces. In the apparel industry, this property is called drape. High flexibility may be either desirable or undesirable, depending on the application. In drainage and erosion control applications, high flexibility is desirable, as it enables the fabric to attain intimate contact with the soil, which it must retain. On the other hand, when used to cap a waste lagoon or form a haul road over soft ground, a fabric of low flexibility may make the work considerably easier by enabling workmen to walk on the fabric while placing it without sinking into the underlying soft soil or waste material. ASTM D 1388 (Option A) is a test to measure flexibility of fabrics. This procedure has been modified slightly by Haliburton et al. (1981) to make it more suitable for the stiffer engineering fabrics. Fabrics with low flexibility (high stiffness) can increase the cost effectiveness of a fabric installation when hand-labor-intensive fabric placement operations control the rate of job progress.

2.2.10 Fatigue

Fatigue is defined as the failure of fabric after repeated application and release of load. Fatigue only appears to be a problem in railroad track rehabilitation and will not be discussed further.

2.3 Hydraulic Properties

The hydraulic properties of fabrics are those that govern the ability of the fabric to pass liquids (and gases) and retain solid particles. The properties encompass piping resistance (related to the fabric pore sizes), permeability (the ease with which water or gas can pass through the fabric), and clogging resistance (the ability to resist reduction in permeability with time).

2.3.1 Piping Resistance

Piping resistance is the ability of a fabric to retain solid particles and is related to the sizes and complexity of the pores or openings in the fabric. Numerous approaches have been taken to measuring the sizes of openings in fabric filters. These have ranged from microscopic examination of thin sections of fabric encased in resin (Masounave et al., 1980), and measurement of the pressure required to cause the bubbling of air through the fabric when submerged in water (British Standards Institute, 1963), to the measurement of the quantity of sand or glass beads of various sizes that can be shaken through the fabric (Calhoun, 1972; Ogink, 1975; Ruddock, 1977). None of the methods has proven entirely satisfactory; however, some variation of the methods using narrowly-sized sand grains or glass beads (sometimes called ballotini) is by far the most widely used.

In the United States, a test of this sort was first developed by Calhoun (1972), primarily for the evaluation of woven fabrics. In his test procedure, sized, rounded sand grains were shaken over samples of woven fabric for 20 min, and the size of sand of which less than 5 percent passed after shaking was taken as the equivalent opening size (EOS) of the fabric. This procedure was then adopted by the U. S. Army Corps of Engineers for evaluating the opening sizes of fabrics. Calhoun's procedure was later modified by adopting glass beads instead of rounded sand and reducing the quantity of material placed on the fabric specimen from 150 to 50 g (5.3 to 1.8 oz). The adoption of glass beads was an attempt to reduce the test variability by eliminating the possible variations between sand samples.

Variables that affect the results of the sieving methods are: (1) sieving time, (2) quantity of particles placed on the fabric sample, (3) the use of beads versus sand, (4) atmospheric humidity, (5) the use of antistatic devices, and (6) the criteria for selection of opening size from the results of the sewing operation.

The EOS is the size of sand or beads of which fewer than 5 percent pass the fabric sample. Other sieving procedures use other percentages (such as 10 or 50 percent) as the sizing percentage. The EOS test should properly refer only to the test in which the percentage passing is 5 percent.

Manufacturers of needle-punched fabrics have objected to the EOS test for having a very low degree of reproducibility for fabrics of this type. Nevertheless, the EOS as described in the U. S. Army Corps of Engineers Guide Specification CW-02215 remains the only broadly accepted method in the United States for evaluating the pore sizes of fabrics. ASTM Committee D35 on Geotextiles is currently working on a standard for determining the opening size of geotextiles that is very similar to the EOS test. The test will be called the apparent opening size (AOS) test.

Note that when any design criterion are used for fabric piping resistance, the method by which the fabric pore size is measured will affect the fabric selected; thus any design criterion must specify the test method by which the fabric pore size is to be evaluated.

2.3.2 Permeability

When engineering fabrics are used in filtration and drainage applications, they must, after installation, have a flow capacity adequate to prevent significant hydrostatic pressure buildup in the soil being drained and must be able to maintain that flow capacity for the range of flow conditions that will exist for that particular installation. For soils, the indicator of flow capacity is the coefficient of permeability as defined by Darcy's law. This can be extended to engineering fabrics as follows:

$$q = kiA = k(\Delta h/L_f)A \qquad \text{Equation 2-1}$$

where

q = hydraulic discharge rate, L^3/T

k = Darcy coefficient of permeability, L/T

i = hydraulic gradient, L/L

A = total cross-sectional area available to flow, L^2

Δh = hydraulic head loss through the fabric, L

L_f = length of flow path (fabric thickness) over which Δh occurs, L

The proper application of this equation requires that fabric thickness be considered. However, since the ease of flow through a fabric, regardless of its thickness, is the property of primary interest, Equation 2-1 can be modified to define a property permittivity, Ψ, as follows:

$$\Psi = \frac{k}{L_f} = \frac{q}{(\Delta h)A} \qquad \text{Equation 2-2}$$

Numerous attempts have been made to measure the permeabilities and permittivities of engineering fabrics. The limitation of most such attempts is that Darcy's law applies only so long as flow through the fabric remains laminar. Unfortunately, this is very difficult to achieve for fabrics, since the hydraulic heads required to assure laminar flow are so small as to be difficult to measure accurately unless many layers of fabric are stacked together to increase the flow path through the fabric with the latter method, the procedure is more complex, and uncertainty exists as to the interaction of the layers with each other. Despite the fact that Darcy's equation does not apply for most measurements of fabric permeability, the values obtained from such measurements are sometimes considered useful as a relative measure of the permeabilities and permittivities of various fabrics. Table 2-1 lists the results of one such set of tests. As shown by comparison with Figure 2-11, the permeabilities of engineering fabrics exceed the permeabilities of most sands and finer grained soils.

2.3.3 Clogging Resistance

Clogging is the reduction in permeability or permittivity of a fabric resulting from blocking of the pores of the fabric by either soil particles or bacterial or chemical encrustations being deposited on or in the fabric. To some degree clogging takes place with all fabrics in contact with soil, and this is why permeabilities of fabrics measured in isolation are of only limited usefulness. However, in normal soil-fabric filtering systems, numerous investigations (Calhoun, 1972; Schober and Teindl, 1979; Haliburton and Wood, 1982; Chen et al., 1981) have shown that for detrimental clogging to occur because of the soil itself, there must be a migration of fine soil particles through the soil matrix to the surface of the fabric. For most

TABLE 2-1

TYPICAL PERMEABILITY VALUES FOR GEOTEXTILES[a]

	Type	Fabric Thickness mm	Coefficient of Permeability, k_f[b] cm/sec	Permittivity, ψ sec^{-1}
NW1	Resin-bonded staple, nonwoven	0.86	1.2×10^{-1}	140
2	Heat-bonded filament, nonwoven	0.74	7.8×10^{-2}	110
3	Heat-bonded filament, nonwoven	0.38	1.3×10^{-2}	34
4	Needle-punched filament, nonwoven	3.00	3.4×10^{-1}	110
5	Needle-punched filament, nonwoven	5.16	3.8×10^{-1}	74
W1	Multifilament, woven	0.51	2.0×10^{-3}	4
W2	Monofilament, woven	0.41	1.8×10^{-2}	45
W3	Slit-film, woven	0.56	2.0×10^{-3}	3
C1	Slit-film, woven with needle punched rap	0.97	1.0×10^{-2}	11

---

[a] Blair et al., 1981.

[b] Tests were performed using falling head test apparatus with head drop from 30 to 10 cm. Turbulent flow assumed; no compression of fabric.

natural soils, internal migration will not take place. However, internal migration may take place under sufficient gradient if one of the following conditions exists:

(1) The soil is very widely graded, having a coefficient of uniformity C_u greater than 20 (Sherard, 1979).

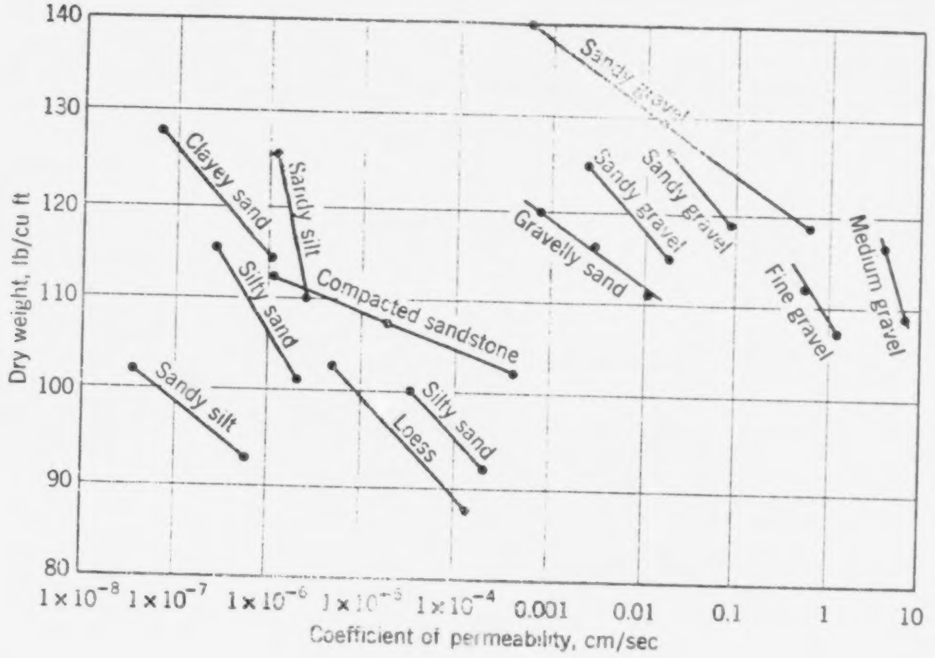
(2) The soil is gap graded.

(3) The soil against the fabric is repeatedly disturbed and goes into suspension in water so that fines are allowed to migrate to the soil/fabric interface.

Calhoun (1972) developed a device for measuring soil-fabric permeability and evaluating the extent to which clogging would take place for a given

FIGURE 2-11

RELATION BETWEEN COEFFICIENT OF PERMEABILITY AND SOIL TYPE
(Cedergren, 1977a)



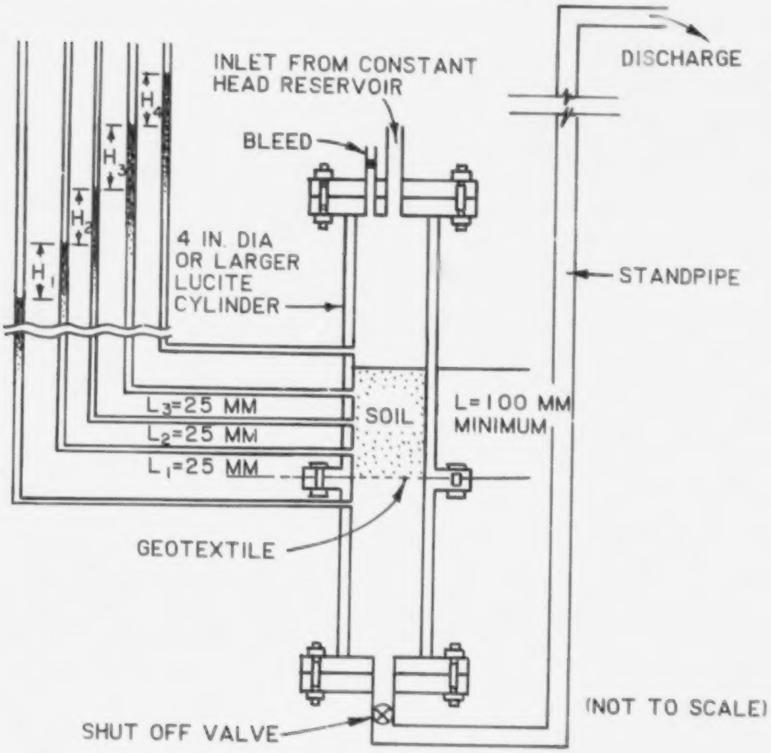
soil-fabric combination. Figure 2-12 illustrates the type of device used for this purpose. After performing extensive tests using the apparatus, Calhoun concluded that if the percentage open area for woven fabric (i.e., the ratio of the area of the openings in the fabric to the total area of the fabric specimen, expressed as a percentage) was sufficiently large, the fabric would be resistant to clogging because of internal migration of fines. This concept proved to be useful at the time, but it was restricted to woven fabrics having distinct, easily measured openings. Later, the U. S. Army Corps of Engineers developed the concept of the gradient ratio--the ratio of the hydraulic gradient across the fabric and the 25 mm (1 in.) of soil immediately above the fabric to the hydraulic gradient between 25 and 75 mm (1 and 3 in.) above the fabric. Accordingly, from Figure 2-12, the gradient ratio is

$$GR = \frac{\dfrac{H_1}{L_1}}{\dfrac{H_2 + H_3}{L_2 + L_3}}$$

Whenever a soil is suspected of being internally unstable, as in cases (1) and (2) above, the particular soil-fabric combination can be evaluated by means of

FIGURE 2-12

DETAIL OF CONSTANT HEAD PERMEAMETER DEVICE USED FOR SOIL-FABRIC PERMEABILITY TESTING


INLET FROM CONSTANT HEAD RESERVOIR
DISCHARGE
BLEED
H_4
H_3
H_2
H_1
4 IN. DIA OR LARGER LUCITE CYLINDER
STANDPIPE
L_3=25 MM
L_2=25 MM
L_1=25 MM
SOIL
L=100 MM MINIMUM
GEOTEXTILE
SHUT OFF VALVE
(NOT TO SCALE)

CORPS OF ENGINEER-TYPE GRADIENT RATIO TEST DEVICE

the soil-fabric test apparatus and the gradient ratio. The third case involves proper construction technique to assure that the engineering fabric is maintained in intimate contact with the soil.

2.3.4 In-Plane Permeability

A great deal of experimentation has recently been devoted to the measurement of the permeability or flow capacity in the plane of fabrics and related products. The ability of certain fabrics and products such as drainage grids, meshes, and panels to transmit significant quantities of fluids in the plane of their structure offers one of the greatest potential uses of these materials in the waste management area. The permeability of relatively thin planar materials parallel to their plane can be expressed by Darcy's law in the same way as flow perpendicular to the plane. However, just as with flow across the plane of a fabric, flow capacity in the plane is best expressed independently of the fabric thickness. The reason is that the thickness of the various materials may differ considerably whereas the ability to transmit fluid under a given head or driving force is the property of interest. The property of in-plane flow capacity of a fabric is termed "transmissivity," θ, and it is derived from Darcy's law as shown below.

$$q = k_p iA$$

$$q = k_p(\Delta h/l)(wt) = \frac{k_p \Delta hwt}{l}$$

$$k_p t = \theta = \frac{ql}{\Delta hw} \qquad \text{Equation 2-3}$$

where

q = hydraulic discharge rate, L^3T^{-1}

k_p = in-plane coefficient of permeability (hydraulic conductivity), L/T^{-1}

Δh = hydraulic head loss, L

l = length of fabric through which liquid is flowing, L

w = width of fabric, L

t = thickness of fabric, L

$\theta = k_p t$ = transmissivity, L^2T^{-1}

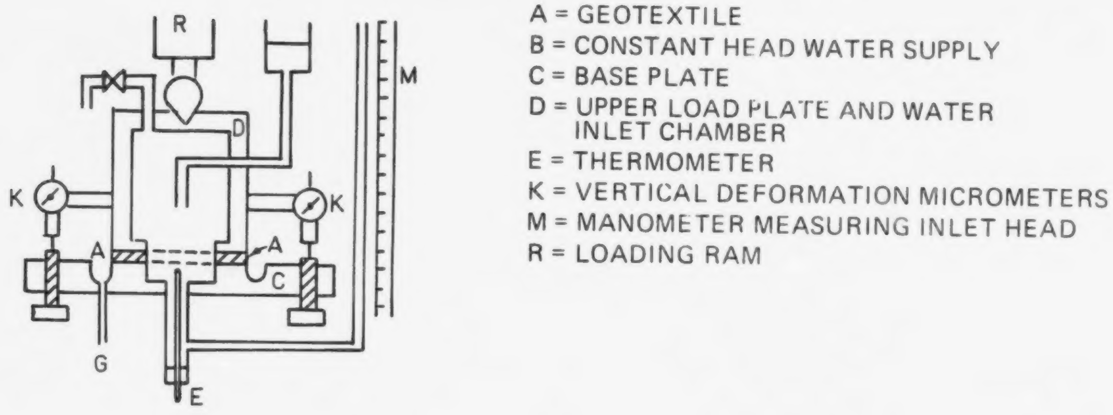
$i = \Delta h/l$ = hydraulic gradient, LL^{-1}

$A = wt$ = total cross sectional area available to flow, L^2

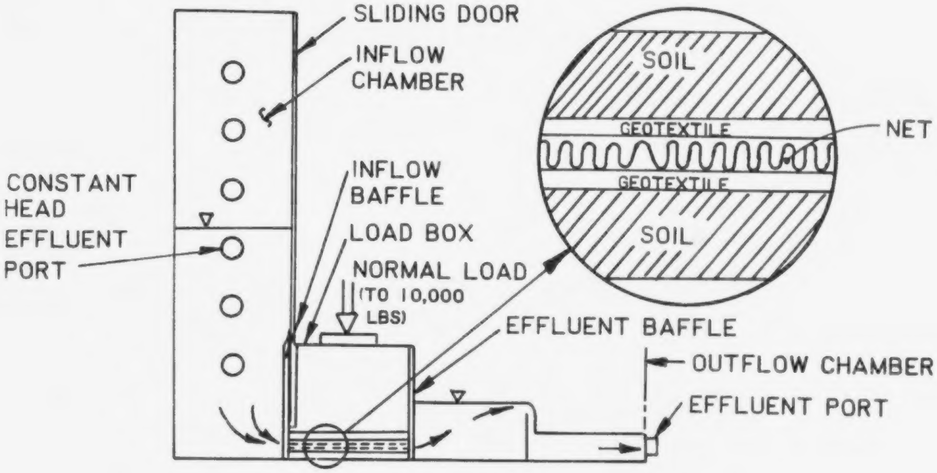
Numerous devices have been developed for measuring fabric and drainage product transmissivity. Two such devices are shown in Figure 2-13. Both devices are capable of measuring transmissivity while a normal pressure is being applied. This is an essential feature of such devices, as the magnitude and nature of the pressure applied to the surface of the material during the tests has a great bearing on the measured value of transmissivity. The measurement of transmissivity has not been standardized in any way. However, certain testing conditions are essential for acquiring meaningful values. The hydraulic head or heads used in the test should approximate the anticipated maximum heads expected in the particular field applications, and the test must be performed with an applied normal pressure that duplicates the pressure that will occur in the field application. This will usually be soil pressure, but it could be liquid or gas pressure or a combination thereof. If the pressure is to be relatively great, it may be important to evaluate the effects of pressure over a long period to ascertain whether creep of the material reduces the

FIGURE 2-13

TEST DEVICES FOR MEASURING THE TRANSMISSIVITY OF FABRICS AND MESHES UNDER LOAD


A = GEOTEXTILE
B = CONSTANT HEAD WATER SUPPLY
C = BASE PLATE
D = UPPER LOAD PLATE AND WATER INLET CHAMBER
E = THERMOMETER
K = VERTICAL DEFORMATION MICROMETERS
M = MANOMETER MEASURING INLET HEAD
R = LOADING RAM
R
D
M
K
K
A
A
C
G
E

a. THE RAUMANN RADIAL FLOW DEVICE (AFTER RAUMANN, 1982)


SLIDING DOOR
INFLOW CHAMBER
CONSTANT HEAD EFFLUENT PORT
INFLOW BAFFLE
LOAD BOX
NORMAL LOAD (TO 10,000 LBS)
EFFLUENT BAFFLE
OUTFLOW CHAMBER
EFFLUENT PORT
SOIL
GEOTEXTILE
NET
GEOTEXTILE
SOIL

b. TRANSMISSIVITY DEVICE FOR MESHES AND NETS (AFTER WILLIAMS, et al 1984) transmissivity over time. Table 2-2 illustrates the range of transmissivities that can be expected from fabrics and related products under a range of normal loads.

2.3.5 Bubbling Pressure

Most engineering fabrics when clean and dry are somewhat hydrophobic, and a small but measurable pressure is required to initiate flow through them. This pressure is referred to as the "critical pressure head" (Mallard and Bell, 1981) or "threshold gradient" (Bell and Hicks, 1983). This pressure depends on the largest pore sizes of the fabric and the wettability of the fibers. The heat-and resin-bonded nonwoven fabrics have the smallest pore sizes and thus would have the highest bubbling pressure. Mallard and Bell (1981) have developed a simple test to measure the head required to initiate flow in a fabric. This quality is only likely to be of significance where flow must take place across a fabric under very low hydraulic heads on the order of 60 mm (2.4 in.) or less.

2.4 Environmental Endurance Properties

2.4.1 Ultraviolet Light Resistance

All the polymers used in the manufacture of engineering fabrics are subject to degradation from exposure to the ultraviolet (UV) portion of sunlight. This chemical degradation can be referred to as "actinism" or "photochemical reaction," but in practice, it is almost universally referred to as "UV degradation." Unprotected polypropylene is the polymer most rapidly degraded by UV radiation, and polyesters are the least rapidly degraded. The various polymers can be made much more resistant to UV attack by incorporating certain chemical additives or an inert pigmenting material, most commonly carbon black, into the polymer formulation. The yarns or fabric may also be coated after manufacture to prevent penetration of the harmful radiation. In most applications, the fabric will be covered by soil, thereby protecting it from extended exposure to sunlight. In these applications, protection is only necessary before final covering. It is recommended that polyester fabrics and fabrics stabilized against UV attack be covered within 30 days, and other fabrics should be covered within 5 days.

Installations such as silt fences and other erosion control applications that expose fabric to sunlight over extended periods require special consideration be given to UV resistance. In these applications the maximum amount of UV protection should be incorporated into the polymer.

The rate of attack by UV light depends on the geographic location of the installation and may be increased by air pollution, repeated wetting and drying, and repeated freezing and thawing. The rate of attack also depends on the construction of the product. Those fabrics having the greatest surface area per unit volume of material will be degraded most rapidly. Thus the slit-film woven fabrics will degrade the most rapidly, and the monofilament woven and the grid structures will degrade the most slowly. Nonwoven fabrics and multifilament woven fabrics will have an intermediate rate of degradation.

Table 2-2

TRANSMISSIVITIES OF FABRICS AND GRIDS UNDER VARIOUS TEST CONDITIONS

Reference	Material and Test Conditions	Normal Load, kPa (psi)	θ m^2/sec (yd^2/sec)
Values calculated for a sand drainage layer	457-mm (18-in.) sand layer having $k = 10^{-2}$ cm/sec		4.6×10^{-5} (5.5×10^{-5})
	305-mm (12-in.) sand layer having $k = 10^{-1}$ cm/sec		3.1×0^{-5} (3.7×10^{-5})
Minimum RCRA[a] requirement	305-mm (12-in.) sand layer having $k = 10^{-3}$ cm/sec		0.3×10^{-5} (0.36×10^{-5})
Williams et al. (1984)	3.2-mm- (1/8-in.-) thick grid; 10 mil polyvinyl chloride and clay on each side	50 (345)	1×10^{-3} (1.2×10^{-3})
	3.2-mm- (1/8-in.-) thick grid; heat-bonded fabric and clay on each side	50 (345)	0.8×10^{-3} (0.95×10^{-3})
	3.2-mm- (1/8-in.-) thick grid; heat-bonded fabric and clay one side, rigid plate on other side	50 (345)	3×10^{-3} (3.6×10^{-3})
	3.2-mm- (1/8-in.-) thick grid; needled fabric and clay on each side	50 (345)	1×10^{-5} (1.2×10^{-5})
	3.2-mm- (1/8-in.-) thick grid; heat-bonded fabric and clay on each side	500 (3,450)	1×10^{-5} (1.2×10^{-5})
Koerner and Sankey (1982)	1 layer needle-punched fabric; 30 percent silt, 70 percent clay mixture on each side	10 (69)	0.1×10^{-5} (0.12×10^{-5})
	1 layer needle-punched fabric; 70 percent silt, 30 percent clay mixture on each side	10 (69)	0.3×10^{-5} (0.36×10^{-5})

(continued)

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[a] Resource Conservation and Recovery Act.

TABLE 2-2 (continued)

Reference	Material and Test Conditions	Normal Load, kPa (psi)	Θ m^2/sec (yd^2/sec)
Koerner and Sankey (1982)	1 layer needle-punched fabric; 85 percent silt, 15 percent clay mixture on each side	10 (69)	1.3×10^{-5} (1.55×10^{-5})
	1 layer needle-punched fabric; 100 percent silt on each side	10 (69)	1.6×10^{-5} (1.9×10^{-5})
	1 layer needle-punched fabric; rigid plates on each side	10 (69)	2.1×10^{-5} (2.5×10^{-5})
Koerner and Bove (1983)	1 layer needle-punched fabric against rigid plates; range for 7 products tested	4.8 (33)	1.2×10^{-5} (1.4×10^{-5}) 6.2×10^{-5} (7.4×10^{-5})
	1 layer needle-punched fabrics against rigid plates; range for 7 products tested	24 (165)	0.6×10^{-5} (0.7×10^{-5}) 1.5×10^{-5} (1.8×10^{-5})
Koerner and Sankey (1982)	1 layer needle-punched fabric, 3.6 mm (0.14 in.) nominal thickness; rigid plates on each side	100 (689)	3.5×10^{-6} (4.2×10^{-6})
	1 layer needle-punched fabric, 4.8 mm (0.19 in.) nominal thickness; rigid plates on each side	100 (689)	6.1×10^{-6} (7.3×10^{-6})
	2 layers needle-punched fabric, 9.6 mm (0.38 in.) nominal thickness; rigid plates on each side	100 (689)	7.1×10^{-6} (8.5×10^{-6})
Raumann (1982)	1 layer needle-punched fabric, against rubber plattens; range for 8 products tested	10 (69)	3×10^{-6} (3.6×10^{-6}) 12×10^{-6} (14.4×10^{-6})
		100 (689)	0.5×10^{-6} (0.6×10^{-6}) 4.1×10^{-6} (4.9×10^{-6})

Outdoor weathering tests (for example, see ASTM D 1435 and E 838) and laboratory-type accelerated weathering tests can be used to evaluate the relative resistance of various products to UV degradation. The Xenon-Arc lamp, when used with special filters as described in ASTM D 4355, correlates well with the spectral distribution of sunlight and is the preferred apparatus for laboratory evaluation of UV resistance. However, because of the factors described above, no generally applicable relationship between outdoor weathering and accelerated weathering tests can be given (Hoerchst Fibers Industries, 1979). The manufacturers of Xenon-Arc weatherometers claim that a 24-hr test cycle in the Xenon-Arc apparatus corresponds to about 10 days of outdoor weathering at average exposure values near Frankfort, Germany, or about 7 days near Miami, Florida. However, many factors can combine to complicate the relationship between weatherometer test results and normal outdoor exposure. These factors include the spectral shifts that occur outdoors when cycling between day and night, the interaction between light exposure and humidity changes, frequency and duration of rainfall, air pollution, and temperature changes that result in freeze-thaw cycles.

2.4.2 Chemical Resistance

2.4.2.1 Resistance To Soil Chemicals

No cases of fabric failure because of attack from chemicals present in a natural soil environment were found in the literature. However, in cases of fabric burial in soils having a very low or very high pH, consideration should be given to the composition of the geotextile selected, as discussed in the following section.

2.4.2.2 Resistance of Common Geotextile Polymers to Chemicals in the Waste Disposal Environment

Fabrics will come into contact with chemical leachate when used in leachate collection systems and in cover designs where they would be below the cover and act as reinforcement or as part of a gas venting system. Several fabric manufacturers were contacted and asked to supply information on the chemical compatibility of their fabrics with various chemicals known to be common in hazardous waste landfills. Several stated that if the chemical environment were known, they would perform tests to determine chemical compatibility of their fabric with specific wastes.

Tables 2-3 and 2-4 present tabulations of the chemical resistance of polypropylene from two manufacturers of polypropylene resin that also manufacture finished geotextiles. Table 2-5 presents a tabulation of chemical resistance of polyester fiber used in the manufacture of polyester geotextiles. Results of chemical compatibility tests supplied by one manufacturer for polypropylene, polyester, and nylon (nylon 6-6) are presented in Table 2-6 for exposure to certain acids, alkalis, inorganic salts, and organic chemicals.

The data presented in the aforementioned tables are only useful for screening purposes for a number of reasons. Differences in plastic formulations and type and levels of additives can have a significant effect on a

TABLE 2-3

CHEMICAL RESISTANCE OF POLYPROPYLENE[a]

Compounds are listed alphabetically.

Legend:
1. Satisfactory (no effect)
2. Generally satisfactory (minor effect)
3. Fair (noticeable effect)
4. Unsatisfactory (severe effect)
– No test data available

A reported value of "4" at room temperature (73°F) does not rule out completely the possibility of using the compound when only short contact time is involved.

COMPOUND	73°F 23°C	120°F 49°C	150°F 66°C	212°F 100°C	COMPOUND	73°F 23°C	120°F 49°C	150°F 66°C	212°F 100°C
Acetaldehyde	1	1	–	–	Alcohol, Amyl	2	2	2	–
Acetate Solvents, Crude	1	–	–	–	Alcohol, Butyl	2	2	2	2
Acetate Solvents, Pure	1	–	–	–	Alcohol, Ethyl	1	1	2	2
Acetic Acid, 10%	1	1	1	1	Alcohol, Isopropyl	1	1	1	1
Acetic Acid, 50%	1	1	1	1	Alcohol, Methyl	1	1	2	2
Acetic Acid, Glacial	1	1	3	–	Almond Oil	1	1	1	–
Acetone (Dimethylketone)	1	1	2	–	Aluminum Chloride	1	1	1	1
Acetophenone	1	1	3	4	Aluminum Nitrate	1	1	1	1
Acetylene	1	–	–	–	Aluminum Sulphate	1	1	1	1
Air	1	1	1	1	Alums	1	1	1	1

(continued)

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[a] Data from Amoco Chemicals Corporation (1980).

TABLE 2-3 (continued)

COMPOUND	73°F 23°C	120°F 49°C	150°F 66°C	212°F 100°C
Ammonia, 25% sol.	1	1	1	–
Ammonia, concentrate	1	1	2	–
Ammonia, gas	1	1	1	–
Ammonium Acetate	1	–	–	–
Ammonium Carbonate	1	1	1	1
Ammonium Chloride	1	1	1	2
Ammonium Hydroxide	1	1	1	1
Ammonium Nitrate	1	1	1	1
Ammonium Sulphate	1	1	1	1
Amyl Acetate	4	4	4	4
Aniline	2	2	3	3
Antimony Trichloride	1	1	2	2
Apple Juice	1	1	1	1
Asphalt (tar)	1	1	1	3
Beer	1	1	1	1
Beet Juice	1	1	1	2
Benzaldehyde	1	–	–	–
Benzene/Benzol	2	4	4	4
Benzene Sulfonic Acid, 10%	1	1	1	1
Benzoic Acid	1	–	–	–
Benzyl Alcohol	1	1	–	–
Bluing	1	1	1	–
Boric Acid	1	1	1	1
Brandy	1	1	–	–
Brine, Acid	1	1	1	–
Bromine Water, Saturated	3	4	4	4
Butane	2	–	–	–
Butanol	1	1	1	1
Butyric Acid	1	1	1	1
Butyl Acetate	3	4	4	4
Butyl Phthalate	1	1	1	1
Calcium Bisulfite	1	1	1	1
Calcium Chloride, 50% sol.	1	1	1	2
Calcium Hypochlorite	1	1	2	3
Calcium Hydroxide	1	1	1	1
Calcium Nitrate	1	1	1	1
Camphor Oil	4	4	4	4
Cane Sugar Liquor	1	–	–	–
Carbon Dioxide, dry	1	1	1	–
Carbon Dioxide, wet	1	1	1	–
Carbon Disulfide	3	4	4	4
Carbon Tetrachloride	2	4	4	4
Castor Oil	1	1	–	–
Caustic Soda, conc.	1	1	1	1
Caustic Soda, dil.	1	1	1	1

COMPOUND	73°F 23°C	120°F 49°C	150°F 66°C	212°F 100°F
Chlorobenzene	2	4	4	4
Chlorine, wet	3	4	4	4
Chlorine, dry	4	–	–	–
Chloroform	3	4	4	4
Chlorosulfonic Acid	4	4	4	4
Cholocate Syrup	1	–	–	–
Chromic Acid, 50%	1	2	2	3
Citric Acid, 10%	1	1	3	4
Clove Oil	2	3	4	4
Coconut Oil	1	–	–	–
Cod Liver Oil	1	–	–	–
Coke Oven Gas	1	–	–	–
Copper Salts	1	1	2	–
Copper Sulphate	1	1	–	–
Core Oils	1	–	–	–
Corn Oil	1	1	2	–
Cottonseed Oil	1	1	2	–
Creosote	1	–	–	–
Creosol	1	–	–	–
Cyclohexane	3	4	4	4
Cyclohexanol	1	2	3	–
Cyclohexanone	2	3	4	4
Decalin	4	4	4	4
Detergent Solution Heavy Duty	1	1	1	2
Diacetone Alcohol	1	1	–	–
Dibutyl Phthalate	1	2	3	–
Diethyl Ether	2	3	4	4
Dimethyl Formamide	1	1	–	–
Dimethylamine	1	1	–	–
Dioctyl Phthalate	3	4	4	4
Dioxane	2	3	4	4
Epichlorohydrin	1	1	–	–
Ethers	3	3	4	4
Ethyl Acetate	2	2	3	4
Ethyl Chloride	4	4	4	4
Ethylene Chloride	2	4	4	4
Ethylene Glycol	1	2	3	4
Ferric Chloride	1	1	1	1
Ferric Sulfate	1	1	1	1
Ferrous Chloride	1	1	1	2
Ferrous Sulfate	1	1	1	1
Formaldehyde, 35% sol.	1	1	2	2
Formalin, 40% sol.	1	–	–	–
Formic Acid,Anhydrous	1	1	2	–
Freon (12,22)	2	–	–	–

(continued)

TABLE 2-3 (continued)

COMPOUND	73°F 23°C	120°F 49°C	150°F 66°C	212°F 100°C	COMPOUND	73°F 23°C	120°F 49°C	150°F 66°C	212°F 100°C
Freon TF	1	2	3	–	Maple Syrup	1	–	–	–
Fuel Oil, No. 2 Distillate	2	3	4	4	Mayonnaise	1	–	–	–
Furfural	4	4	4	4	Meat Sauce	1	1	1	–
Gasoline	4	4	4	4	Mennen's "Skin Bracer"	1	1	1	–
Gelatin	1	1	1	1	Mercurochrome	1	–	–	–
Glucose	1	1	1	1	Mercuric Chloride	1	1	1	2
Glue	1	–	–	–	Mercury	1	1	1	–
Glycerine	1	1	1	–	Methanol, 100%	1	1	2	2
Heptane	2	4	4	4	Methyl Isobutyl Ketone	2	4	4	4
Hexane	2	4	4	–	Methylene Chloride	3	4	4	4
Household Detergent	1	1	2	–	Methyl Isobutyl Carbinol	1	1	–	–
Hydraulic Oil	2	3	4	–	Milk	1	1	–	–
Hydrobromic Acid, 50%	1	1	3	–	Mineral Oil (White)	1	2	4	4
Hydrochloric Acid, 38% conc	2	2	3	–	Molasses	1	–	–	–
Hydrocyanic Acid	1	–	–	–	Motor Oil	2	3	4	4
Hydrofluoric Acid 40%	1	1	2	3	Mustard Paste	1	–	–	–
Hydrofluoric Acid, 50%	1	–	–	–	Natural Gas	1	–	–	–
Hydrogen Fluoride	1	–	–	–	Neat's - Foot Oil	1	1	1	–
Hydrogen	1	–	–	–	Nickel Chloride	1	1	1	2
Hydrogen Peroxide	1	1	1	–	Nickel Sulfate	1	1	1	1
Hydrogen Peroxide, 3% sol.	1	–	–	–	Nitric Acid, dil.	1	1	1	1
Hydrogen Peroxide, 28% sol.	1	2	3	4	Nitric Acid, 30%	1	1	–	–
Hydrogen Peroxide, dry	1	1	2	–	Nitric Acid, 50%	1	4	4	4
Hydrogen Sulfide, wet	1	1	2	–	Nitric Acid, Fuming	3	4	4	4
Iodine Solution, H_2O	1	–	–	–	Nitrobenzene	2	3	3	–
Iodine in Alcohol	1	–	–	–	Nitrogen Oxide	1	–	–	–
Isooctane	2	3	4	4	Nitrous Acids	3	–	–	–
Kerosene	2	3	4	4	Nutmeg Oil	4	4	4	4
Lacquer	1	–	–	–	Oleic Acid	1	2	2	3
Lacquer plus solvent	1	–	–	–	Olive Oil	1	1	2	3
Lactic Acid, 80%	1	1	1	–	Orange Juice	1	–	–	–
Lead Acetate	1	1	1	1	Oxalic Acid, 50%	1	1	1	–
Lemon Oil	3	4	4	4	Oxygen Gas	1	1	1	1
Ligroine	1	1	–	–	Palmitic Acid	1	1	1	1
Lime Sulfur	1	–	–	–	Peanut Oil	1	2	3	4
Linseed Oil	1	1	2	–	Peppermint Oil	1	4	4	4
Liquified Petroleum Gas(LPG)	2	3	4	–	Percholoroethylene	2	3	4	4
Lubricating Oil	2	3	4	–	Perchloric Acid	1	–	–	–
Lye	1	–	–	–	Phenol	1	1	1	1
Magnesium Chloride	1	1	1	2	Phenol, 5% sol.	1	1	1	1
Magnesium Hydroxide	1	1	1	1	Phosphoric Acid, 85%	1	1	2	2
Magnesium Nitrate	1	1	1	1	Phosphoric Acid, 50%	1	1	1	2
Magnesium Sulfate	1	1	1	1	Phosphoric Acid, 25%	1	1	1	1
Malic Acid	2	3	3	–	Photographic Sol.	1	1	1	–
Manganese Salts	1	1	1	1	Picric Acid	1	–	–	–

(continued)

TABLE 2-3 (continued)

COMPOUND	73°F 23°C	120°F 49°C	150°F 66°C	212°F 100°C
Plating Sol. (any)	1	1	1	1
Potassium Bichromate/Sulfuric Acid/Water (5/100/5)	1	2	3	4
Potassium Carbonate	1	1	1	1
Potassium Chlorate	1	1	1	2
Potassium Chloride	1	1	1	2
Potassium Hydroxide, 50%	1	1	1	–
Potassium Iodide	1	–	–	–
Potassium Permanganate,20%	1	2	2	–
Potassium Sulfate	1	1	1	1
Pyridine	1	1	1	1
Rice Bran Oil	1	1	1	–
Rosin, light	1	–	–	–
Safflower Oil	1	1	2	–
Sauerkraut	1	–	–	–
Shellac	1	–	–	–
Shoe Polish, Liquid	1	–	–	–
Silicone Oil	1	–	–	–
Silver Nitrate	1	1	1	1
Soap Solution, 5%	1	1	1	–
Soapless Detergent	1	–	–	–
Sodium Bicarbonate	1	1	1	1
Sodium Bisulfate	1	1	1	1
Sodium Bisulfite	1	1	1	1
Sodium Borate	1	–	–	–
Sodium Bromide	1	1	1	1
Sodium Carbonate, 3% aq.	1	1	1	1
Sodium Carbonate, sat. sol.	1	1	1	1
Sodium Chlorate	1	1	1	1
Sodium Chloride, 10% aq.	1	1	1	1
Sodium Chloride, sat. sol.	1	1	1	1
Sodium Cyanide	1	1	1	1
Sodium Hydroxide, conc.	1	1	1	1
Sodium Hydroxide, 50%	1	1	1	1
Sodium Hypochlorite, conc.	1	2	3	4
Sodium Hypochlorite, 5%	1	2	3	4
Sodium Metaphosphate	1	–	–	–
Sodium Nitrate	1	1	1	1
Sodium Palmitate, sol.5%	1	–	–	–
Sodium Perborate	1	–	–	–
Sodium Phosphate, Alkaline	1	1	1	1
Sodium Phosphate, Acid	1	1	1	1
Sodium Phosphate, Neutral	1	1	1	1
Sodium Silicate	1	1	1	1
Sodium Sulfate	1	1	1	–
Sodium Sulfide	1	1	1	–
Sodium Sulfite	1	1	1	–

COMPOUND	73°F 23°C	120°F 49°C	150°F 66°C	212°F 100°C
Sodium Thiosulfate,hypo.	1	1	1	–
Soybean Oil	1	1	1	–
Spindle Oil	1	1	4	4
Stearic Acid	1	–	–	–
Succinic Acid	1	1	1	–
Sulfate Liquor	1	–	–	–
Sulfur	3	4	4	4
Sulfur Chloride	3	4	4	4
Sulfur Dioxide, dry	1	–	–	–
Sulfur Dioxide, wet	1	–	–	–
Sulfuric Acid, 100%	2	4	4	4
Sulfuric Acid, 98%	2	3	4	4
Sulfuric Acid, 50%	1	1	2	3
Sulfuric Acid, 10%	1	1	1	2
Sulfurous Acid	1	1	1	–
Tannic Acid	1	1	1	1
Tartaric Acid	1	1	1	–
Tea	1	1	1	1
Tetrahydrofuran	2	3	3	–
Tetralin	4	4	4	3
Toluene	2	4	4	4
Tomato Juice & Soup	1	1	1	1
Transformer Oil	1	2	4	4
Trichloroacetic Acid, 2N	1	1	1	–
Trichloroethylene	2	3	4	4
Trisdium Phosphate	1	1	1	–
Turpentine	2	3	4	4
Two-Stroke Oil (outboard motor oil)	1	1	4	4
Urea	1	1	1	1
Vanilla	1	1	–	–
Varnish	1	–	–	–
Vaseline	1	1	2	3
Vaseline Oil	1	1	2	3
Vinegar	1	1	1	–
Vinegar, White	1	1	1	–
Water, Distilled & Tap	1	1	1	1
Water, Brine	1	–	–	–
Water, Sea	1	–	–	–
Wax Crayon	1	–	–	–
Wheat Germ Oil	1	1	1	–
Whisky	1	1	1	–
White Spirits	4	4	4	4
Wines	1	1	1	–
Xylene	2	4	4	4
Zinc Chloride	1	1	1	1
Zinc Sulfate	1	1	1	1

TABLE 2-4

STRENGTH RETENTION OF POLYPROPYLENE YARNS AFTER EXPOSURE TO CERTAIN CHEMICALS[a,b]

Chemicals	After 24 Hours	After 1 Week	After 4 Weeks
ACIDS			
10 percent Acetic Acid	99	99	99
40 percent Acetic Acid	100	98	99
Glacial Acetic Acid	104	102	99
5 percent Benzoic Acid (in Isoproporal)	101	100	102
5 percent Hydrochloric Acid	103	97	97
13.3 percent Hydrochloric Acid	97	100	99
Conc. Hydrochloric Acid (Tech. grade)	101	97	102
10 percent Nitric Acid	103	101	102
40 percent Nitric Acid	101	101	97
Conc. Nitric Acid	102	95	93
10 percent Oxalic Acid	105	104	101
40 percent Peracetic Acid	100	98	88
60 percent Acid	103	100	102
Conc. Phosphoric Acid	100	99	100
5 percent Salicylic Acid (in Methanol)	98	99	101
10 percent Sulfuric Acid	102	99	102
40 percent Sulfuric Acid	104	97	101
Conc. Sulfuric Acid	87	56	40
10 percent Trichloroacetic Acid	100	99	103
BASES			
25 percent Sodium Hydroxide	100	100	100
50 percent Sodium Hydroxide	101	99	100
Oxidizing Agents	100	99	100

(continued)

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[a] Data from Phillips Fiber Corporation (n. d.).

[b] Tests performed on industrial denier yarns using ASTM D 2256; pulled at 8.5 mm/sec; strength reported as percentage of strength of unexposed yarns.

TABLE 2-4 (continued)

Chemicals	After 24 Hours	After 1 Week	After 4 Weeks
31.4 percent Hydrogen Peroxide	100	99	100
50 percent Sodium Hypochlorite	98	98	98
SALTS			
5 percent Ferric Chloride	99	100	99
5 percent Sodium Chlorite (Textone)	99	99	98
OTHER CHEMICALS			
Acetone	98	100	100
Acetonitrile	101	101	100
Acetophenone	102	98	100
Acrylonitrile	102	101	100
Analine	102	98	101
Benzene	97	97	98
Benzaldehyde	98	101	99
Benzyle Alcohol	99	99	101
5 percent Biphenyl (in Methanol)	101	99	99
Butyl Acetate	98	101	99
Butyl Stearate	96	98	101
Carbon Disulfide	98	97	99
Carbon Tetrachloride	99	98	100
Chlorobenzene	97	99	99
Chloroform	98	97	99
Cotton Seed Oil	98	100	100
M-Cresol	102	101	99
Cyclohexane	99	98	100
Cyclohexanone	97	101	97
Decalin	100	98	101
Dibutyl Phthalate	97	96	98
1, 4 - Dioxane	100	101	100
Ether	98	98	98

(continued)

TABLE 2-4 (continued)

Chemicals	After 24 Hours	After 1 Week	After 4 Weeks
Ethyl Acetate	100	97	97
Ethylbenzene	96	101	100
Ethylene Glycol	98	101	100
Formaldehyde	101	100	102
5 percent Iodine (in CCL)	101	98	102
Linseed Oil	97	99	98
Methyl Salicylate	102	101	99
N, N - Dimethylocetamide	102	99	101
Nitrobenzene	100	98	99
5 percent Ortho-Phenyl Phenon (in Methanol)	98	99	97
5 percent Para-Dichlorobenzene (in Ether)	101	98	100
Petroleum Ether	101	98	99
60/40 Phenol/Tetrachloroethylene	101	99	100
Phenyl Hydrozene	97	100	101
Polypropylene Glycol	98	99	98
Pyridine	101	101	100
5 percent Sodium Dithionite	98	99	98
Tetrachloroethylene	97	98	96
Tetralin	100	99	98
Toluene	96	99	99
1, 2, 4, - Trichlorobenzene	103	102	102
Trichloroethylene	102	97	100
5 percent 1, 2, 4, - Trichloro-5-Nitrobenzene (in Ether)	97	99	99
5 percent 2, 4, 6, - Trichlorophenol (in Methanol)	98	99	98
1, 2, 4, - Trichlorotoluene	103	100	101
Toluene	96	99	99
Xylene	99	99	98

TABLE 2-5

CHEMICAL RESISTANCE OF POLYESTER (from Hoerchst Fibers Industries 1979)

Resistance to saturated aqueous solutions of inorganic chemicals after various exposure times

Chemicals aqueous solutions	pH	Exposure time in month							
		1	3	6	12	1	3	6	12
		Tenacity ratio (%)				Knot tenacity ratio (%)			
Aluminium suphate	2.9	100	100	100	100	100	100	100	100
Ammonium chloride	5.1	100	100	100	100	100	100	100	100
Ammonium nitrate*	4.8	100	100	100	100	100	100	100	100
Ammonium sulphate	4.6	100	100	100	100	100	100	100	100
Ammonium sulphide 40 %	9.6	50	d.	d.	d.	55	d.	d.	d.
Calcium chloride*	7.2	100	100	100	100	100	100	100	100
Calcium nitrate*	3.9	100	100	100	100	100	100	100	100
Copper sulphate	3.5	100	100	100	100	100	100	100	100
Ferric chloride	0.8	100	100	100	100	100	100	100	100
Ferrous sulphate	3.0	100	100	100	100	100	100	100	95
Lead acetate	5.7	100	100	100	100	100	100	100	100
Magnesium chloride*	4.0	100	100	100	100	100	100	100	100
Magnesium sulphate	6.6	100	100	100	100	100	100	100	100
Nickel sulphate*	4.5	100	100	100	100	100	100	100	100
Potassium bichromate	3.7	100	100	100	100	100	100	100	96
Potassium bromide	6.5	100	100	100	100	100	100	100	100
Potassium carbonate	13.1	100	100	100	96	100	93	91	84
Potassium chlorate	6.9	100	100	100	100	100	100	100	100
Potassium chloride*	8.0	100	100	100	100	100	100	100	95
Potassium chromate*	9.4	100	100	100	100	100	100	100	93
Potassium nitrate	8.8	100	100	100	100	100	100	100	100
Potassium perchlorate	9.9	100	100	100	100	100	100	100	100
Potassium permanganate	9.7	100	100	100	94	100	99	98	88
Potassium sulphate	7.5	100	100	100	100	100	100	100	100
Silver nitrate 25 %	4.6	100	100	100	100	100	100	100	100
Sodium ammonium hydrogen phosphate	8.2	100	100	100	100	100	100	100	86
Sodium bicarbonate	7.8	100	100	100	100	100	100	100	100
Sodium bisulphite	4.1	100	100	94	94	100	100	100	100
Sodium carbonate	11.2	100	100	100	94	100	100	100	93
Sodium chlorate	7.4	100	100	100	100	100	100	100	100
Sodium cloride	7.4	100	100	100	100	100	100	100	100
Sodium nitrate	8.3	100	100	100	100	100	100	100	100
Sodium perchlorate*	5.8	100	100	100	100	100	100	100	100
Sodium sulphate	5.4	100	100	100	100	100	100	100	100
Sodium tetraborate	9.3	100	100	100	100	100	100	100	95
Sodium thiosulphate*	7.4	100	100	100	100	100	100	100	95
Zinc chloride*	2.4	100	100	100	100	100	100	100	100
Zinc sulphate*	4.0	100	100	100	100	100	100	100	100
d. = destroyed	* 50 %								

Resistance to inorganic and organic acids after various exposure times

Chemicals	pH	Exposure time in months							
		1	3	6	12	1	3	6	12
		Tenacity ratio (%)				Knot tenacity ratio (%)			
Acetic acid 15 %	2.0	100	100	100	100	100	100	100	100
Acetic acid conc.	0.1	100	100	100	100	100	100	100	100
Acetic anhydride		100	100	100	100	100	100	100	97
Benzoic acid*		100	100	100	100	100	100	100	100
Boric acid**	3.5	100	100	100	100	100	100	100	100
Chlorosulphonic acid		d.i.	d.i.	d.i.	d.i.	d.i.	d.i.	d.i.	-
Chromic acid**		98	96	85	83	85	74	73	72
Citric acid 15 %	1.5	100	100	100	100	100	100	100	100
Citric acid 25 %	1.2	100	100	100	100	100	100	100	100
Formic acid conc.	< 0.1	100	100	100	100	100	100	100	100
Hydrochloric acid 15 %	< 0.1	100	100	100	100	100	100	100	100
Hydrochloric acid 20 %	< 0.1	93	83	72	35	80	71	63	41
Hydrochloric acid 30 %	< 0.1	78	52	32	16	54	45	23	d.
Hydrochloric acid 37 %	< 0.1	43	20	d.	d.	47	22	d.	d.
Hydrofluoric acid 10 %		97	96	95	93	99	95	88	70
Hydrofluoric acid 20 %		95	94	93	86	93	87	86	70
Hydrofluoric acid 38...40 %		94	86	70	48	92	85	66	47
Lactic acid conc	0.7	100	100	100	100	100	100	100	100
Malic acid 25 %	1.3	100	100	100	100	100	100	100	94
Nitric acid 15 %	< 0.1	100	100	100	100	100	100	100	100
Nitric acid 20 %	< 0.1	90	85	69	52	81	68	66	45
Nitric acid 30 %	< 0.1	87	66	52	26	64	62	43	23
Nitric acid 50 %	< 0.1	57	27	10	d.	45	23	d.	-
Nitric acid 65 %	< 0.1	7	d.	d.	d.	d.	d.	d.	d.

(continued)

NOTE: d. = destroyed.

* Saturated alcoholic solutions.

** Aqueous solution.

TABLE 2-5 (continued)

Chemicals	pH	Exposure time in months							
		Tenacity ratio (%)				Knot tenacity ratio (%)			
		1	3	6	12	1	3	6	12
Oxalic acid**		100	100	100	100	100	100	100	100
Phosphoric acid 20 %	0.6	98	97	95	92	100	97	90	86
Phosphoric acid 50 %	0.1	98	98	96	95	100	100	100	98
Phosphoric acid 85 %	< 0.1	100	100	100	100	100	100	100	100
Stearic acid *		100	100	100	100	100	100	100	100
Sulphuric acid 15 %	< 0.1	100	100	100	100	100	100	100	100
Sulphuric acid 38 % (battery acid)	< 0.1	100	100	100	100	100	100	97	89
Sulphuric acid 50 %	0.1	98	95	94	92	96	95	91	75
Sulphuric acid 70 %	0.1	88	83	76	72	83	77	70	66
Sulphuric acid 90 %	0.1	d.i.	d.i.	d.i.	d.i.	d.i.	d.i.	d.i.	d.i.
Sulphuric acid conc. 98 %	< 0.1	d.i.	d.i.	d.i.	d.i.	d.i.	d.i.	d.i.	d.i.
Caustic soda solution 2 %	12.8	90	86	74	50	86	83	61	57
Caustic soda solution 5 %	12.5	48	45	15	d.	55	45	19	d.
Caustic soda solution 10 %	12.4	47	d.	d.	d.	38	d.	d.	d.
Caustic soda solution 15 %	12.1	d.	d.	d.	d.	d.	d.	d.	d.
Caustic soda solution 20 %	11.8	d.	d.	d.	d.	d.	d.	d.	d.
Caustic soda solution 30 %	11.2	d.	d.	d.	d.	d.	d.	d.	d.
Diethylamine	13.5	79	75	69	55	78	76	67	49
Hydrazine 2 %	10.6	95	88	86	76	95	88	79	75
Hydrazine 5 %	10.8	92	76	51	15	83	73	35	-
Triethanolamine	13.3	92	86	79	66	90	83	69	68
Urea 50 %	10.4	98	97	97	91	100	100	93	92

(continued)

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* Saturated alcoholic solutions.

** Aqueous solution.

TABLE 2-5 (continued)

Resistance to alkalis after various exposure times

Chemicals	pH	Exposure time in months Tenacity ratio (%) 1	 3	 6	 12	 Knot tenacity ratio (%) 1	 3	 6	 12
Ammonia	8	97	96	89	86	100	100	100	93
Ammonia	9	96	95	88	85	100	97	85	83
Ammonia	10	95	92	87	84	95	92	84	82
Ammonia 2 %	11.4	83	68	41	d.	83	64	25	d.
Ammonia 5 %	12.2	65	d.	d.	d.	64	d.	d.	d.
Ammonia 10 %	12.5	15	d.	d.	d.	11	d.	d.	d.
Ammonia 15 %	13.2	d.	d.	d.	d.	d.	d.	d.	d.
Ammonia 20 %	13.4	d.	d.	d.	d.	d.	d.	d.	d.
Calcium hydroxide 15 %	12.4	95	80	73	33	88	87	70	-
Calcium hydroxide 30 %	12.4	93	79	71	32	71	84	69	-
Calcium hydroxide 50 %	12.4	92	64	29	d.	70	80	62	d.
Caustic potash solution 0,1 %	12.5	98	97	95	90	95	90	88	86
Caustic potash solution 2 %	13.4	88	87	80	62	92	85	74	68
Caustic potash solution 5 %	13.7	81	71	51	18	83	78	49	23
Caustic potash solution 10 %	14.0	71	32	d.	d.	50	38	d.	d.
Caustic potash solution 20 %	14.0	7	d.	d.	d.	11	d.	d.	d.
Caustic potash solution 30 %	14.0	d.	d.	d.	d.	d.	d.	d.	d.
Caustic potash solution 40 %	14.0	d.	d.	d.	d.	d.	d.	d.	d.
Caustic soda solution 0.1 %	12.1	100	100	100	94	-	-	-	-

Resistance to organic chemicals (solvents) after various exposure times

Chemicals	Exposure time in months Tenacity ratio (%) 1	 3	 6	 12	 Knot tenacity ratio (%) 1	 3	 6	 12
Acetone	100	100	100	100	100	100	100	100
Amyl acetate	100	100	100	100	100	100	100	100
Aniline	100	100	100	100	100	100	100	100
Benzaldehyde	100	100	100	100	100	100	100	100
Benzcatechin**	100	100	100	100	100	100	99	98
Benzene	100	100	100	100	100	100	100	100
Benzoic acid amide*	100	100	100	100	100	100	100	100
Benzyl alcohol	100	92	78	53	100	100	90	80
Butanol	100	100	100	100	100	100	100	100
Butyl acetate	100	100	100	100	100	100	100	100
Carbon tetrachloride	100	100	100	100	100	100	100	98
Chloramine	100	100	100	98	100	100	100	90
Chloroform	100	100	100	100	100	100	100	100
m-cresol	100	100	100	100	100	100	100	100
Cyclohexanone	100	100	100	100	100	100	100	100
Cyclohexylamine	86	83	68	57	90	77	70	65
Crude oil	100	100	100	100	100	100	98	90
Diacetone alcohol	100	100	100	100	100	100	100	100
Dimethyl formamide	100	100	100	100	100	100	100	96
Dimethyl sulphoxide	100	100	100	100	100	100	100	100
Epichlorhydrin	100	100	100	100	100	100	100	100
Ethanol	100	100	100	100	100	100	100	100
Ether	100	100	100	100	100	100	100	100
Ethyl acetate	100	100	100	100	100	100	100	100

(continued)

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* Saturated alcoholic solution.

** Saturated aqueous solution.

TABLE 2-5 (continued)

Resistance to organic chemicals (solvents) after various exposure times

Chemicals	Exposure time in months							
	1	3	6	12	1	3	6	12
	Tenacity ratio (%)				Knot tenacity ratio (%)			
Formaldehyde 30 %	100	100	100	100	100	100	100	100
Formamide	100	100	100	100	100	100	100	100
Fuel oil EL	100	100	100	100	100	89	86	82
Glycol	100	100	100	100	100	100	100	100
n-Hexylamine	21	d.	d.	-	49	d.	d.	-
Hydroquinone*	100	100	100	100	100	100	100	100
Isopropyl alcohol	100	100	100	100	100	100	100	100
Methyl acetate	100	100	100	100	100	100	100	100
Methyl alcohol	100	100	100	100	100	100	100	100
Methylene chloride	100	100	100	100	100	100	100	100
Methyl ethyl ketone	100	100	100	100	100	100	100	100
Mineral oil	100	100	100	100	100	100	100	100
Nitrobenzene	100	100	100	100	100	100	100	100
Petroleum	100	100	100	100	100	100	100	100
Phenol***	100	100	100	100	100	100	100	100
m-Phenylene diamine**	100	100	100	100	100	100	100	100
2-Phenylethylalcohol	100	100	100	100	100	100	100	100
Phloroglucinol*	100	100	100	100	100	100	100	100
Pyridine	100	100	100	100	100	100	100	100
Pyrogallol	100	100	100	100	100	100	100	100
Resorcinol**	100	100	100	100	100	100	100	100
White spirit	100	100	100	100	100	100	100	100
Styrene	100	100	100	100	100	100	100	100
Tetrachloroethane	100	95	93	92	100	89	85	81
Toluene	100	100	100	100	100	100	100	100
Trichloroethylene	100	100	100	100	100	100	100	100
Trimethylamine	80	24	d.	d.	82	56	d.	d.
Turpentine	100	100	100	100	100	100	100	97
Xylene	100	100	100	100	100	100	100	98

Resistance to fuels after various exposure times

Chemicals	Exposure time in weeks				
	1	3	7	14	28
	Tenacity ratio (%)				
Petroleum	100	100	100	100	100
Petrol, normal-grade	100	100	100	100	100
Petrol, super-grade	100	100	100	100	100
Diesel	100	100	100	100	100
Benzene	100	100	100	100	100
Jet propellant JP 1	100	100	100	100	100
Jet propellant JP 4	100	100	100	100	100
Isooctane	100	100	100	100	100

(continued)

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* Saturated alcoholic solution.
** Saturated aqueous solution.
*** 50 percent alcoholic solution.

TABLE 2-5 (concluded)

Resistance to fertilizers after various exposure times

Chemicals	pH	Exposure time in months							
		1	3	6	12	1	3	6	12
			Tenacity ratio (%)			Knot tenacity ratio (%)			
Ammonium sulphate*, dry		100	97	96	84	100	98	91	90
Ammonium sulphate**, moist	4.2	92	92	91	83	96	94	87	85
Blaukorn		93	92	91	90	100	97	89	88
Blaukorn, moist 50 %	4.6	92	90	88	87	82	87	85	84
Calcium nitrate		96	95	95	92	97	96	88	83
Calcium nitrate, moist 50 %	5.7	92	91	91	88	96	90	86	82
Calcium cyanamide, not oiled, dry		95	93	91	90	93	92	89	86
Calcium cyanamide, not oiled, wet 10 %	11.5	85	73	66	13	88	74	71	20
Grünkorn		94	93	88	86	96	93	90	83
Grünkorn, moist 50 %	6.7	86	86	85	83	86	86	85	83
Lime, slaked		90	89	89	86	91	86	85	80
Lime, slaked, moist 50 %	12.3	88	78	64	d.	86	75	62	d.
NPK 12/12/18, dry*		95	94	92	89	99	96	95	92
NPK 12/12/18 moist 50 %	4.9	94	93	89	85	88	85	83	82
NPK 15/15/15, dry*		97	96	95	90	100	98	96	94
NPK 15/15/15 moist 50 %	4.0	96	93	92	88	85	83	80	79
Rotkorn		98	96	93	92	98	94	93	90
Rotkorn, moist 50 %	3.8	97	96	92	91	91	80	78	76
Thomas meal*		90	89	88	86	92	88	84	83
Thomas meal, moist 50 %	12.3	80	74	61	35	77	75	64	60
Urea		99	98	97	93	100	100	94	93
Urea, moist 50 %	10.4	98	97	97	91	100	100	93	92
Urea, 35 % Ammonium nitrate 35 % Water, 30 %	7.3	-	95	94	93	-	94	87	83

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* Fertilizer was used in normal commercial condition.

** Fertilizer was mixed with water to form a 50 percent mixture.

TABLE 2-6

EFFECT OF CHEMICAL EXPOSURE ON BREAKING STRENGTH AND APPEARANCE[b] OF SYNTHETIC FIBERS

	Exposure Conditions			Strength Loss[a] Caused by Chemical Exposure		
Acids	Concentration percent	Temperature °C (°F)	Time Hours	Polypropylene	Polyester	Nylon 6-6
Chromic acid	10.0	21.1 (70)	10	none[c]	--	considerable**
Hydrobromic acid	10.0	21.1 (70)	10	none	none	slight
Hydrochloric acid	10.0	21.1 (70)	1,000	none	none	considerable
Hydrochloric acid	10.0	71.1 (160)	10	none	none	considerable
Hydrochloric acid	37.0	21.1 (70)	1,000	none	moderate	--
Hydrochloric acid	37.0	71.1 (160)	10	none	moderate	--
Hydrofluoric acid	10.0	21.1 (70)	10	none	slight	slight
Nitric acid	10.0	21.1 (70)	1,000	none	none	considerable
Nitric acid	10.0	98.9 (210)	10	none	none	degraded
Nitric acid	70.0	21.1 (70)	10	none	slight	--
Nitric acid	95.0	21.1 (70)	1,000	considerable[c]	--	--
Phosphoric acid	10.0	98.9 (210)	10	none	none	slight
Phosphoric acid	85.0	21.1 (70)	10	none	none	degraded
Sulfamic acid	10.0	21.1 (70)	10	none	none	none
Sulfuric acid	10.0	21.1 (70)	1,000	none	none	considerable
Sulfuric acid	10.0	98.9 (210)	10	none	none	considerable
Sulfuric acid	60.0	21.1 (70)	10	none	none	degraded
Sulfuric acid	60.0	21.1 (70)	1,000	none	none	--
Sulfuric acid	60.0	98.9 (210)	10	none	slight	--
Sulfuric acid	80.0	21.1 (70)	1,000	none	moderate	--
Sulfuric acid	96.0	21.1 (70)	1,000	none	--	--
Alkalis						
Ammonium hydroxide	58.0	21.1 (70)	10	none	none	none
Ammonium hydroxide	58.0	21.1 (70)	1,000	none	degraded	none
Sodium hydroxide	10.0	21.1 (70)	1,000	none	considerable	none
Sodium hydroxide	10.0	98.9 (210)	10	none	degraded	none
Sodium hydroxide	40.0	21.1 (70)	1,000	none	degraded	none
Sodium hydroxide	40.0	98.9 (210)	10	none	degraded	none
Sodium orthosilicate	1.0	98.9 (210)	10	none	none	none
Saturated Salt Solution						
Aluminum chloride		21 (70)	1,000	none	none	none
Ammonium thiocyanate		93 (200)	10	none	none	none
Calcium chloride		93 (200)	10	none	none	none
Copper sulfate		21 (70)	1,000	none	none	none
Ferric chloride		21 (70)	1,000	none	none	none
Ferric chloride		93 (200)	10	none[c]	none	appreciable
Silver nitrate		93 (200)	10	none[c]	none	none
Sodium nitrate		93 (200)	10	none	none	none
Zinc chloride		93 (200)	10	none	none	degraded
Organic Chemical						
Acetic acid	100	21 (70)	1,000	none	none	slight
Acetone	100	21 (70)	1,000	none	none	none
Benzaldehyde	100	21 (70)	1,000	none	none	none
Benzene	100	21 (70)	1,000	none	none	none
Butyrolactone	100	93 (200)	10	none	none	none
Chlorobenzene, mono-	100	21 (70)	1,000	none	none	none

(continued)

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[a] Change in breaking strength of fibers (test procedure not reported).
none = 90 percent or more of original strength retained.
slight = 80 to 98 percent of original strength retained.
moderate = 60 to 79 percent of original strength retained.
considerable = 20 to 59 percent of original strength retained.
degraded = 0 to 19 percent of original strength retained.

[b] Data from the Du Pont Company.

[c] Specimen was discolored by the exposure.

TABLE 2-6 (continued)

	Exposure Conditions			Strength Loss[a] Caused by Chemical Exposure		
Organic Chemical	Concentration percent	Temperature °C (°F)	Time Hours	Polypropylene	Polyester	Nylon 6-6
Chlorobenzene, mono-	100	93 (200)	10	slight	none	none
m-Cresol	100	21 (70)	1,000	none	none	degraded
m-Cresol	100	93[c] (200)	10	none	degraded[d]	degraded
m-Cresol	100	202 (200)	10	degraded	degraded	--
Cyclohexanone	100	93 (200)	10	degraded	none	none
p-Dichlorobenzene	100%(Powder)	21 (70)	1,000	none	none	none
Dimethyl acetamide	100	93 (200)	10	none	none	none
Dimethyl formamide	100	153 (307)[c]	10	degraded	degraded	none
Dimethyl sulfoxide	100	93 (200)	10	none	none	none
Ethylene glycol	100	21 (70)	1,000	none	none	none
Formaldehyde	10% in H_2O	21 (70)	1,000	none	none	none
Formic acid	92% in H_2O	93 (200)	10	none	none	--
Methyl salicylate	100	21 (70)	1,000	none	none	none
Methylene chloride	100	21 (70)	1,000	none	none	none
Naphthalene	100%(Powder)	21 (70)	1,000	none	none	none[d]
Nitrobenzene	100	21 (70)	1,000	none	none	none[d]
Nitrobenzene	100	93 (200)	10	none	none	none
Oxalic acid	Sat.Sol.[b] in H_2O	21 (70)	1,000	none	none	none
Perchlorethylene	100	93 (200)	10	appreciable	none	none
Perchlorethylene	100	121 (250)[c]	10	degraded	none	none
Phenol	10% in H_2O	21 (70)	1,000	none	slight	degraded
Phenol	100	21 (70)	10	none	degraded	degraded
o-Phenylphenol	10% in CH_3OH	21 (70)	1,000	none	none	none
Propylene carbonate	100	93 (200)	10	none	none	none
Pyridinc	100	21 (70)	1,000	none	none	none
Stoddard solvent	100	93 (200)	10	none	none	none
Tetrachloroethane	100	21 (70)	1,000	none	none	none
Tetrachloroethane	100	93 (200)	10	none	moderate	none
Trifluoroacetic acid	100	21 (70)	1,000	none[d]	degraded	degraded
Turpentine	100	21 (70)	1,000	none	none	none
m-Xylene	100	93 (200)[c]	10	none	none	none
m-Xylene	100	139 (282)[c]	10	degraded	none	slight

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[c] Boiling point of chemical agent.
[d] Specimen was discolored by the exposure.

given plastic's reaction to a given chemical. One cannot assume that a plastic fiber or fabric will behave similarly with similar chemicals. Also, the concentrations of chemicals likely to come into contact with fabrics in hazardous waste management applications will in many cases be far less than the concentrations used in the chemical compatibility tests commonly available. However, chemicals present in hazardous waste disposal sites may be present in combinations that cause effects that would not be caused by a single reagent. In addition, fabrics installed in waste containment facilities are expected to function for at least 30 years without failure. Thus the need for long-term chemical resistance testing for periods of a year or more are clearly indicated. Finally, in many waste containment applications, the fabric will be under long-term static stress because it has to bridge gaps in drainage gravel when used in filtering and drainage applications and when put into direct tension in reinforcement applications. Environmental stress cracking may take place under these conditions and may lead to failure of the fabric, whereas the fabric might show little deterioration in a similar chemical environment that is not under stress.

Short-term screening tests of the type described in ASTM D 543 are seldom predictive of service life. This type of test measures the change in a property of an item after being immersed in a liquid reagent for 7 days. The weight change, dimensional change, and tensile strength change are all used to evaluate the effects of immersion. Swelling potential is an important consideration in evaluating fabrics for potential use in a chemical environment because excessive swelling may cause a reduction in the fabric porosity and permeability, leading to a fabric's failure as a filter or drainage material. To evaluate strength reduction under static load, it is necessary to perform creep and creep rupture tests such as in ASTM D 2990, in which test specimens are statically loaded while immersed in a liquid of composition comparable to that likely to be found in a specific application. The following discussion of specific plastics is based on the conventional screening tests such as ASTM D 543.

Polypropylene shows good chemical resistance to aqueous solutions of most acids, bases, and inorganic salts, even at high concentrations, it is subject to attack by strong oxidizing agents. No known solvent exists for polypropylene at room temperature. However, polypropylene will absorb chemicals to an extent that depends on temperature and the polarity of the organic material. Absorption increases with increasing temperature and decreasing polarity of the media. The effect of absorption is to cause swelling and a reduction of tensile strength. Chlorinated hydrocarbons cause swelling of polypropylene at room temperature and some will dissolve polypropylene at 71.1° C (160° F).

Hoerchst Fibers, a major manufacturer of polyester fibers and geotextiles in the United States, has published extensive information on the chemical resistance of their fibers. Their work indicates that polyester is resistant to aqueous solutions of organic salts except 40-percent solutions of ammonium sulfide and potassium carbonate. Polyester shows good resistance to organic and dilute inorganic acids, even at low pH values. However, degradation occurs and becomes rapid as the acids become concentrated.

Polyester shows very limited resistance to alkalis and is particularly sensitive to ammonia and sodium hydroxide (caustic soda) solutions. At concentrations above 15 percent, polyester yarns are completely destroyed by these chemicals.

Polyester is resistant to very many organic chemicals. Exceptions are some amines such as chloramine, cyclohexylamine, hexylamine, and trimethylamine. Polyester is slightly attacked by benzyl alcohol and tetrachlorethane at room temperature, causing a reduction in strength with time. Polyester is very resistant to fuels and bituminous materials.

Only limited information was obtained on the chemical resistance of nylon, since this material is used only to a very limited extent in geotextiles. Nylon is reported to Have good resistance to aromatic and aliphatic solvents, common automotive oils and fuels, and refrigerants. Nylon is attacked by strong acids, bases, and phenol. Nylon is also attacked by aqueous solutions of ferric chloride and zinc chloride.

Literature available from Du Pont, the sole manufacturer of Kevlar, states that the fiber has excellent chemical resistance except for a few strong acids (Du Pont Company, 1976). More detailed information on the properties of this material was not presented in the literature for this fiber.

2.4.2.3 Chemical Resistance Tests of Finished Fabrics

Calhoun (1972) reported the results of short- and long-term tests on fabrics being marketed in 1970. Five of the fabrics were polypropylene monofilament woven fabrics, one was a polypropylene staple-needled fabric, and one was a polyvinylidene chloride woven fabric. The fabrics were tested for resistance to alkali, acid, JP-4 fuel, and toluene. For the short-term alkali tests, equal amounts of sodium hydroxide and potassium hydroxide were dissolved in water to make a pH 13 solution, and fabric specimens were immersed in this solution at 60°-65.5° C (140°-150°F) until the fabric reached a constant weight. For the short-term acid tests, the fabrics were immersed in a hydrochloric acid solution adjusted to a pH of 2 and maintained at a temperature of 60°-65.5° C (140°-150° F) for 14 days. The effect of JP-4 fuel was determined by immersing fabric samples at room temperature for 24 hours and 7 days. The long-term immersion tests were carried out at room temperature with (a) an equal part solution of sodium hydroxide and potassium hydroxide adjusted to pH 10, (b) a pH 3 hydrochloric acid solution, and (c) toluene.

The effects of these chemicals on the fabrics were measured by comparing the tensile strength of the specimens after immersion with specimens that had not been immersed. For the fabrics tested, none lost more than 10 percent strength in the short-term exposure or 2 percent in long-term exposure to the alkali solutions. None of the fabrics showed any significant decrease in strength because of exposure to acid in either short- or long-term tests. In the fuel immersion tests, the needled polypropylene lost approximately 30 percent of its original strength after 1 week of immersion in JP-4 fuel, and it lost 57 percent of its machine direction strength in the long-term immersion tests in toluene and 30 percent in the cross machine direction. One of the polypropylene monofilament woven fabrics had 14 percent strength loss after JP-4 fuel immersion, but it showed no effect from toluene. The polyvinylidene chloride fabric and one polypropylene woven fabric lost more than 10 percent strength after 12 and 6 months immersion in toluene, respectively. No significant deterioration occurred with the other cloths.

Table 2-7 provides a summary of the responses of geotextile plastics to a variety of chemicals. The table is a summary of data extracted from previous tables. The chemicals selected are, with a few exceptions, the same chemicals used by Anderson and Brown (1981) in their evaluation of the susceptibility of clay liners to chemical attack.

Currently the ASTM Committee on Geotextiles is working to develop a standard method for "Resistance of Geotextiles to Chemical Environments." The test method as currently proposed evaluates the geotextile in terms of weight change and loss of tensile strength from exposure. The test method is similar to D 543 and allows for a minimum immersion time of 1 month and testing at

TABLE 2-7

EFFECTS OF VARIOUS CHEMICALS ON GEOTEXTILE PLASTICS[a]

Chemical	Concentration Percent	Effect of Chemicals on		
		Polyester	Polypropylene	Nylon
Acetic acid	100 (glacial)	None	None	Substantial
Sulphuric acid	10[b] (pH < 1)	None	None	Substantial
Sodium hydroxide	10[b] (pH = 12.4)	Destroyed	None	None
Aniline	100	None	None	--
Acetone	100	None	None	None
Ethylene glycol	100	None	None	None
Isooctane	100	None	Some	--
Xylene	100	Some	Some	None
Chlorobenzene	100	Some	Some	None
Methylene chloride (dichloromethane)	100	None	Substantial	None
Ferrous sulfate	Saturated[b]	None	None	--

---

[a] Consensus of data available to the author for room-temperature exposure of at least 1 month.

[b] Aqueous solution.

various temperatures. Efforts to validate the test by round-robin testing have indicated very poor agreement between participating laboratories, and the method is currently under revision.

2.4.3 Biological Resistance

No known cases exist of a geotextile failures resulting from attack by soil microorganisms, even though some fabric installations are more than 20 years old. Certain forms of bacteria are known to cause the precipitation of ferric hydroxide and sulfides; these precipitates, along with the oxidizing bacterial colonies, cause slimes that have been observed on fabrics used in drainage systems. These slimes can potentially clog fabric filters, though there have been no reported instances of fabrics actually being attacked by these or other organisms. No evidence exists at this time to suggest that fabrics would be more likely to clog from these formations than would granular materials used for the same purpose.

In an investigation of the failure of a concrete block erosion control revetment on a freshwater lake, algae was observed to be growing on the surface of a needle-punched nonwoven fabric that had been placed as a filter beneath the blocks (Lee, 1977). In this installation, samples of the fabric were removed from the site and tested for permeability. Laboratory tests revealed that the combination of algal growth and entrapped soil particles had reduced fabric permeability from 4×10^{-1} cm/sec (1100 ft/day) to 5×10^{-3} cm/sec (14 ft/day). Though the algal growth was concluded not to have contributed to the failure of the revetment, it is apparent that given a constantly moist environment and sufficient sunlight, algae could contribute to the clogging of a fabric used for erosion control. In the application just described the algae was only found on those areas between the revetment blocks exposed to direct sunlight. Thus protecting an erosion control fabric from direct sunlight after installation serves the dual purpose of eliminating growth of algae as well as reducing deterioration from ultraviolet light.

Although the synthetic fibers used in the manufacture of geotextiles appear to be impervious to microorganisms, tests have been developed to evaluate the effect of mildew and microorganisms on fabrics (e.g. ASTM Methods G 21, G 22, G 29, and D 3083, and the American Association of Textile Chemists and Colorists test for mildew and rot resistance of textiles). These tests are listed in Appendix B.

In addition to microorganisms, fabrics are subject to damage by burrowing animals and by the growth of plant roots through fabric pores. Though no investigations of damage by root growth are known, it seems plausible that plant roots could reduce the permeability of fabric filters, especially when fabrics are used in landfill covers and cover soil depths are 0.45 to 0.6 m (1-1/2 to 2 ft) or less.

2.4.4 Miscellaneous Environment Effects.

2.4.4.1 Temperature Extremes

Calhoun (1972) performed tests on polypropylene and polyvinyldene chloride fabrics to evaluate their embrittlement at low temperature. None of the fabrics evidenced cracking at temperatures to minus -51° C (-60° F). In a series of strength tests on the same fabrics performed at temperatures from -17.7° to 82.2° C (0° to 180° F), strength differences did not appear to be significant, and there was no consistent trend of strength change with test temperature. The results did show that the strain at failure increased somewhat as temperature was increased from -17.7° to 82.2° C (0° to 180° F).

Allen et al. (1982) reported that tensile tests of a representative sampling of fabric types tested at room temperature (22° C, or 71.6° F) and in a subfreezing environment (-12° C, or 10.4° F) showed elongations at failure and decreased significantly for the polypropylene fabrics tested and for heat-bonded fabrics. The modulus and strength of heat-bonded fabrics was shown to increase with decreasing temperature.

2.4.4.2 Freeze-thaw Cycles

Calhoun (1972) subjected fabrics to 300 2-hr cycles of freezing and thawing in which the temperature was varied between -17.7° and 4.4° C (0° and 40° F) and found that there was no change in physical strength properties after cycling. Allen et al. (1982) found no effect on strength after subjecting a representative sampling of fabric types to 50 24-hr cycles of freezing and thawing in fresh water.

2.4.4.3 Long-term Water Immersion

Haliburton et al. (1978) reported that 5-week immersion of four polypropylene woven fabrics in artificial seawater reduced the postimmersion strengths by 6 to 32 percent. No explanation was given for the strength losses, and the weight gain for the two fabrics with the greatest strength loss was less than 2 percent.

Tests by Allen et al. (1982) did not reveal any reduction in strength from immersion in saline water for 50 24-hr cycles of freezing and thawing.

Christopher (1983b) evaluated the performance of several installations in which a polypropylene monofilament woven fabric was used beneath rip-rap for shoreline erosion protection. After 10 years of exposure to alternating cycles of salt water immersion and drying, samples of fabric were excavated and tested. In most cases, there was less than a 20% decrease from the strength of the new fabric, and in some cases only a 5% decrease or less was noted.

3.0 DESIGN OF FILTERS AND DRAINAGE SYSTEMS

3.1 Requirements for Conventional (Granular) Filters

Rules for the design of filters and drainage systems using granular materials are well established and have been used successfully for many years. These rules were originally proposed by Terzaghi (1982) and have been reevaluated and elaborated on by many investigators. See, for example, Thanikachalam et al. (1972), Sherard et al. (1984a), and Sherard et al. (1984b). The rules are based on the premise that to perform correctly as a soil filter, the filter must retain the soil to be protected and be sufficiently permeable to prevent buildup of hydrostatic pressure. In some applications, the granular material acts as both a filter and a conduit for the fluid to be drained. The criteria for sizing of a granular soil filter is based on the gradation of the filter relative to that of the soil as follows

$$\frac{D_{15} \text{ filter}}{D_{85} \text{ of soil being drained}} \le 5 \qquad \text{Equation 3-1}$$

$$\frac{D_{50} \text{ filter}}{D_{50} \text{ of soil being drained}} \le 25 \qquad \text{Equation 3-2}$$

where

D_{85} , D_{50} , and D_{15} are the particle sizes of the material, of which 85, 50, and 15 percent by weight are smaller, respectively

For fine-grained soils such as silts and clays, as well as for sands and coarser materials, the above criteria have been found to be conservative (Sherard et al., 1984a).

For protecting fine-grained soils such as silts and clays, a sand filter having

$$D_{15} \text{ filter} \le 0.3 \text{ mm} \qquad \text{Equation 3-3}$$

has been shown to be conservative (Sherard et al., 1984b). Sherard states that neither the plasticity nor the dispersiveness of the clay has a significant influence on the filter criteria.

In most applications, the granular material used as a filter does not in itself have sufficient permeability to carry the flow quantities needed. The flow capacity of trenches and blankets are therefore usually augmented by a layer of coarse gravel and/or perforated or slotted drain pipe. To prevent piping of the granular filter into the pipe, the following criteria have been established (Cedergren, 1977b) (Department of the Army, 1978):

For slotted pipes: $$\frac{D_{50} \text{ filter}}{\text{slot width}} > 1.2 \qquad \text{Equation 3-4}$$

For perforated pipes: $$\frac{D_{50} \text{ filter}}{\text{hole diameter}} > 1.0 \qquad \text{Equation 3-5}$$

In addition to a piping requirement, a permeability criterion is specified to assure that the filter is substantially more permeable than soil being protected (Cedergren, 1977b). This is expressed as

$$\frac{D_{15} \text{ filter}}{D_{15} \text{ of soil being drained}} \geq 5 \qquad \text{Equation 3-6}$$

However, it can not be assumed that if the permeability criterion of Equation 3-6 is met that a drain has adequate flow capacity. When designing a drainage system, it is essential to evaluate the potential inflows at all points in the system and design the drain including selection of the drain pipe to carry the expected flows based on seepage principles.

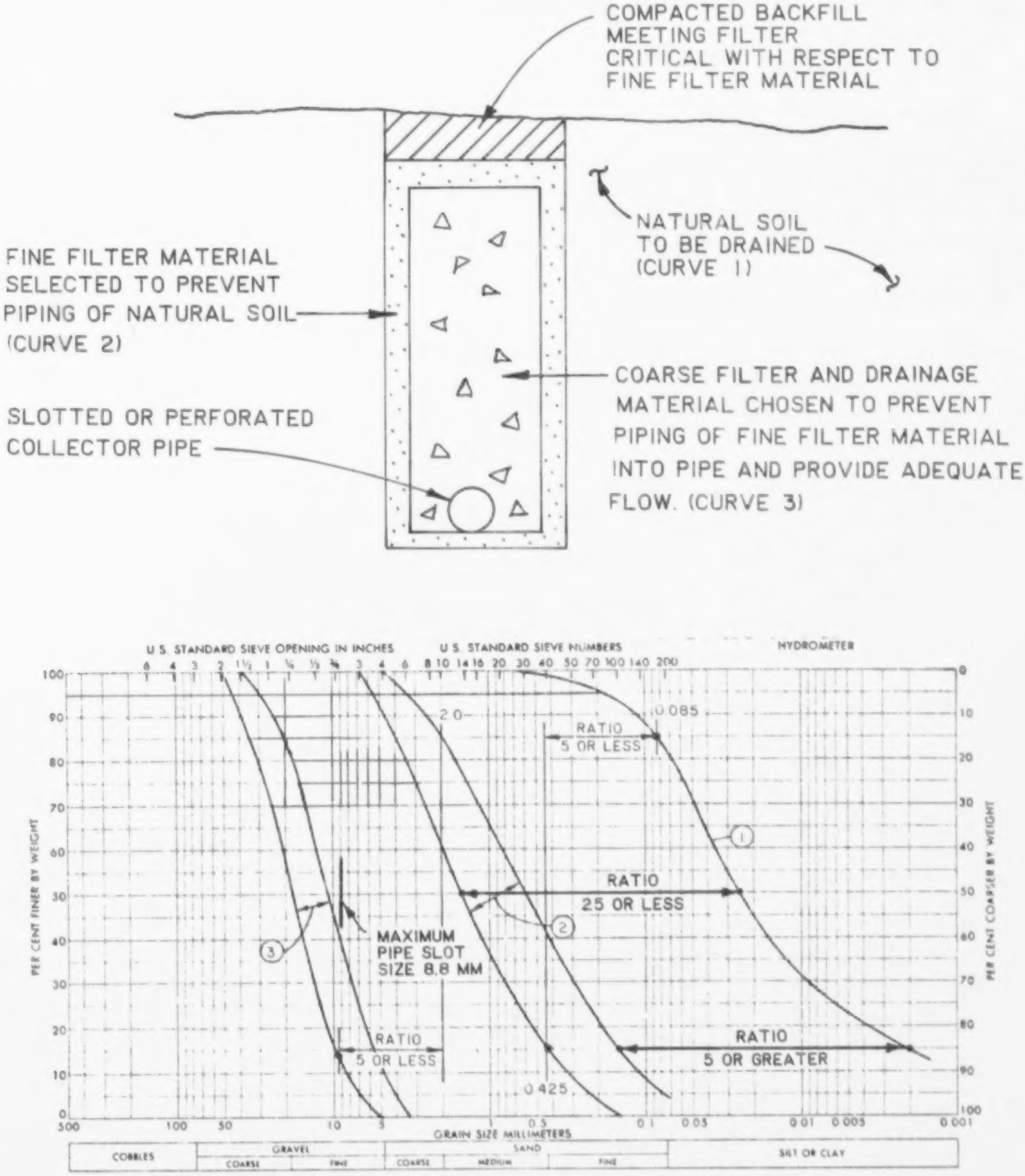
Figure 3-1 illustrates the use of conventional filter criteria in the design of a graded filter for a ground-water interceptor trench. Note that as a practical matter, the filter material must be specified as a range of possible gradations and that the criteria must be applied to account for the variations in the allowable gradation range.

3.2 Requirements for Fabric Filters and Drains

In cases such as that illustrated in Figure 3-1 it is often cost effective to substitute a properly selected fabric for one or more of the components of a conventional granular filter/drainage system. When used in such applications, engineering fabrics must fulfill the same requirements imposed on granular filters: the fabric must prevent piping of the soil to be drained and remain sufficiently permeable over the life of the project to prevent the buildup of hydrostatic pressures. Numerous approaches have been taken to developing filter criteria for engineering fabrics. These have been summarized by numerous authors, including Hoare (1982), Lawson (1982), and Rycroft and Dennis Jones (1982). All criteria have some means of evaluating the piping potential of fabrics, and attempt to assure adequate permeability

FIGURE 3-1

DESIGN OF A GRADED FILTER FOR A GROUNDWATER INTERCEPTOR TRENCH


COMPACTED BACKFILL MEETING FILTER CRITICAL WITH RESPECT TO FINE FILTER MATERIAL
NATURAL SOIL TO BE DRAINED (CURVE 1)
FINE FILTER MATERIAL SELECTED TO PREVENT PIPING OF NATURAL SOIL (CURVE 2)
COARSE FILTER AND DRAINAGE MATERIAL CHOSEN TO PREVENT PIPING OF FINE FILTER MATERIAL INTO PIPE AND PROVIDE ADEQUATE FLOW. (CURVE 3)
SLOTTED OR PERFORATED COLLECTOR PIPE
U.S. STANDARD SIEVE OPENING IN INCHES
6 4 3 2 1½ 1 ¾ ½ ⅜
U.S. STANDARD SIEVE NUMBERS
3 4 6 8 10 14 16 20 30 40 50 70 100 140 200
HYDROMETER
PER CENT FINER BY WEIGHT
PER CENT COARSER BY WEIGHT
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100
2.0
0.085
RATIO 5 OR LESS
RATIO 25 OR LESS
RATIO 5 OR LESS
RATIO 5 OR GREATER
MAXIMUM PIPE SLOT SIZE 8.8 MM
0.425
①
②
③
500 100 50 10 5 1 0.5 0.1 0.05 0.01 0.005 0.001
GRAIN SIZE MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT OR CLAY

by measuring the permeability of the fabric or the hydraulic performance of the fabric-soil system. In addition to the hydraulic requirements, fabrics must also possess adequate strength to withstand the stresses associated with installation and any subsequent stressing.

3.2.1 Hydraulic Requirements

The most widely known criteria in the United States for selection of fabrics for filtration are those proposed by Calhoun (1972), whose work was incorporated by the U. S. Army Corps of Engineers into a construction guide specification for the selection of fabrics for filtration and erosion control. The criteria for piping was based on evaluation of the fabric opening size as determined by the EOS test described in Section 2, related to an empirical criteria for sizing of holes in perforated pipe. Calhoun's criteria stated the following:

a. Adjacent to granular materials containing 50 percent or less by weight of material passing the No. 200 sieve and having little or no plasticity:

(1) $$\frac{D_{85} \text{ of soil to be drained (mm)}}{\text{EOS (mm)}} > 1$$

(2) Open area is not to exceed 40 percent.

b. Adjacent to soils having little or no cohesion and containing more than 50 percent silt by weight:

(1) EOS is no larger than the opening in a No. 70 sieve.

(2) Open area is not to exceed 10 percent.

Calhoun also states that, where possible, one should use fabric with the greatest open area allowed by the criteria. Also no fabric should have the EOS smaller than the No. 100 sieve, and the percent open area should never be less than 4 percent. These original recommendations were made when very little nonwoven fabric was being used for filtration and drainage applications, and Calhoun's recommendations apply primarily to woven fabrics. The percentage of open area, for example, can only be determined on fabrics with distinct two-dimensional openings such as those found in woven fabrics. Subsequent work by the U. S. Army Corps of Engineers at the U. S. Army Engineer Waterways Experiment Station led to adoption of the gradient ratio test as a means of evaluating both woven and nonwoven fabrics. As published in a revised guide specification, the U. S. Army Corps of Engineers (Department of the Army, 1977) criteria are based on the EOS and gradient ratio tests. To satisfy the criteria,

a. For the particular soil-fabric combination being proposed

$$\text{Gradient ratio} \leq 3$$

b. For fabric adjacent to soils containing 50 percent or less by weight fines

$$\frac{D_{85}\text{ of the soil to be drained (mm)}}{\text{EOS (mm)}} \leq 1$$

c. For fabric adjacent to all other types of soil the EOS

$$\text{No. 70 sieve (mm)} \geq \text{EOS} \geq \text{No. 100 sieve (mm)}$$

d. Filter fabrics should not be used for soils having gradations in which 85 percent or more passes the No. 200 sieve.

e. When possible, it is preferable to specify a fabric with openings as large as allowed by the criteria.

The U. S. Army Corps of Engineers criteria given above limit the range of soils for which fabric can be used. The U. S. Forest Service, in a report by Steward et al. (1977), presented filter criteria nearly identical to those used by the U. S. Army Corps of Engineers without a limitation on the use of fabric for soils with more than 85 percent of the particles passing the No. 200 sieve.

Haliburton and Wood (1982) have substantiated the U. S. Army Corps of Engineers gradient ratio criterion for evaluating the clogging potential of soils under severe hydraulic conditions. In soils subject to internal erosion (suffosion) or instability, fines are carried by flowing water through the coarser particles, pass through the fabric and are carried away, or they build up on (or in) the fabric causing clogging and pressure buildup behind it. Haliburton and Wood found that as the amount of fines piping through the soil increased, the gradient ratio increased slowly to a value of about 3 and then increased rapidly, with small further increases in soil fines content.

Though the gradient ratio test provides a direct measure of fabric performance with a given soil, the test is relatively time-consuming and expensive, and it is soil-specific. In applications where only small flows and low hydraulic gradients are involved, Haliburton et al. (1981) recommended that the fabric be more permeable than the adjacent soil and that clogging potential not be evaluated. Haliburton suggested use of a fabric with a permeability at least 10 times greater than the permeability of the soil.

Bell and Hicks (1983), after an extensive review of test methods and use criteria for geotextiles, proposed a set of recommendations for the use of fabrics in filter applications. Their criteria are based on the EOS test, fabric permeability, and the use of monofilament woven fabrics for severe hydraulic conditions. Their recommendations are summarized as follows:

a. To provide sufficient initial permeability

(1) $$\frac{k_{geotextile}}{k_{soil}} > 1$$

(2) Maximum allowable threshold gradient is to be considered for very low gradients. Allowable threshold gradient is to be selected by designer.

b. To provide confinement of the soil to be protected:

(1) EOS (in mm) < D_{85} of soil to be drained or .210 mm (No. 70 sieve) ≥ EOS ≥ .149 mm (No. 100 sieve), whichever is greater,

(2) Designer is to select a flexible fabric when soil surface is rough but no specific requirements are given.

c. To resist plugging of geotextile and significant reduction of permeability of system below initial geotextile permeability:

(1) For well-graded or uniform soil and clean water, a 10-percent minimum open area is recommended for woven fabrics. No open area recommendation is made for nonwoven fabrics.

(2) For gap-graded soil and/or dirty water, use monofilament woven fabric with EOS > 6 times the average size of the fine fraction or suspended solids is recommended. Fabric should have a minimum of 10 percent open area.

(3) For soils having more than 85 percent finer than a No. 200 sieve, an open area between 4 and 10 percent is recommended for woven fabrics. No recommendation is made for nonwoven fabrics.

From the above review it seems apparent that, at least in the United States, most criteria for the selection of fabrics are based in whole or in part on criteria originally proposed by the U. S. Army Corps of Engineers. These criteria depend on certain specific test procedures described in Chapter 2 for their validity. All the criteria are based on the principle that the geotextile will always remain in contact with the soil to be drained, and that the soil structure next to the fabric does not move. None of the criteria are intended to resist loss of soil though the fabric openings in those cases where soil can move freely next to the fabric. However, proper installation procedures (described later), will prevent particle movement for all the applications described in this handbook.

The recommended hydraulic requirements for filtration and drainage applications in hazardous waste landfills appear in Table 3-1. These

TABLE 3-1

RECOMMENDED CRITERIA FOR SELECTION OF GEOTEXTILES FOR FILTRATION/DRAINAGE APPLICATIONS

I. Hydraulic Requirements

A. Gap-graded soils, soils having coefficient of uniformity,[a] $C_u > 20$.

(1) Piping Resistance Requirement

EOS (in mm) $\leq D_{85}$ of soil to be drained

For soil having D_{85} finer than the No. 70 sieve,

0.149 mm (No. 100 sieve) $\leq$ EOS (in mm) $\leq$ 0.210 mm (No. 70 sieve)

(2) Permeability/Clogging Resistance Requirement

Woven fabrics: percent open area ≥ 10 percent

Nonwoven fabric: gradient ratio ≤ 3

B. All soils not covered by A, above.

(1) Piping Resistance

EOS (in mm) $\leq D_{85}$ of soil to be drained

For soil having a D_{85} finer than the No. 70 sieve,

0.149 mm (No. 100 sieve) $\leq$ EOS (in mm) $\leq$ 0.210 mm (No. 70 sieve)

(2) Permeability/Clogging Resistance Requirement.

k fabric ≥ k soil

Alternate requirement (applicable to woven fabrics only)

Percent open area > 4

(continued)

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[a] Coefficient of uniformity, $C_u = \frac{D_{60}}{D_{10}}$.

TABLE 3-1 (continued)

II. Physical Requirements

Property	Test	Minimum Value
Tensile strength	ASTM D 1682 Grab test using CRE testing machine operated at 305 mm (12 in.) per minute; 25 mm (1 in.) × 50 mm (2 in.) jaws.	334 N (75 lb) in both principal directions
Elongation at failure	ASTM D 1682 Grab test using CRE testing machine operated at 305 mm (12 in.) per minute; 25 mm (1 in.) × 50 mm (2 in.) jaws.	20 percent in both principal directions
Tear resistance	ASTM D 1117 Trapezoidal Tear.	222 N (50 lb) in both principal directions
Puncture resistance	ASTM D 3787, modified by replacing the steel ball with an 8 mm diameter steel rod having a hemispherical tip.	156 N (35 lb)
Flexibility	No quantitative requirement. Fabric flexibility should be considered with respect to the particular installation and the need to maintain intimate contact with soil to be protected. Use flexible fabric when soil surface is rough. Use ASTM D 1388 to evaluate geotextiles.	

III. Environmental Resistance Requirements

A. Fibers used in the manufacture of the engineering fabric shall consist of a long-chain synthetic polymer consisting of at least 85 percent by weight propylene, ester, or vinylidene-chloride. If any polymers other than those specified are proposed, they must meet the requirements set forth in Table 3-2.

B. The engineering fabric shall be of a composition resistant to ultraviolet light and weathering such that it shall retain at least 90 percent of its initial tensile strength after 100 hr of exposure in an Xenon- Arc Weatherometer, as specified in ASTM D 4355.

C. Fabric placed in any location where it may potentially be subjected to contact from a chemical environment other than that of natural soil, shall be evaluated for its resistance to the anticipated chemicals to which it may come in contact.

TABLE 3-2

ENVIRONMENTAL RESISTANCE REQUIREMENTS FOR GEOTEXTILES

Treatment	Test Method	Required Result[a]
Alkali treatment	Special[b]	90 percent
Fuel immersion	Special[b]	90 percent
Acid treatment	Special[b]	85 percent
Low temperature strength	ASTM D 1682 at -18° C.	85 percent
High temperature strength	ASTM D 1682 at 82° C.	80 percent
Oxygen pressure	ASTM D 572	90 percent
Freeze-thaw	ASTM C 666	85 percent
Weatherometer	ASTM G 23	65 percent
Long-term immersion	Special[b]	80 percent
Low-temperature brittleness	ASTM D 746	No failures at minus 51.1° C (60° F)
Weight change in water	CRC-C-575	Less than 1.0%

[a] Ratio of strength after treatment to strength for untreated fabric specimens tested according to ASTM D 1682, grab test using CRE testing machine operated at 305 mm (12 in.) per minute and 25 mm × 25 mm jaws.

[b] The test methods are special U. S. Army Corps of Engineers tests. They are described in Calhoun (1972).

recommendations are based on the criteria discussed above and on the experiences of U. S. Army Corps of Engineers personnel in the use of fabrics in filtration and drainage. The recommendations are divided into two categories. Category A is for severe applications where the possibility exists for movement of soil fines in suspension. Category B is for all other applications where internal migration of fines will not take place. In both categories, allowance is made for the reduction in initial fabric permeability that occurs when a fabric is implanted in soil.

3.2.2 In-plane Permeability (Transmissivity)

Certain engineering fabrics and specially designed composite structures can be substituted for granular drainage material and drainage pipe. When these materials are considered for use, the same information about expected flow rates or regulatory requirements for flow capacity must be known as if a conventional material were used. These materials must also fulfill the requirements for filters discussed in previous paragraphs. Though thick-needle punched fabrics and composite structure drainage panels and drainage grids have been used in several sites, no history of performance exists for materials in this application as does for fabrics in filtration applications. Selection of these materials for use as drains should be made with caution and only after performing transmissivity tests of the type described in Chapter 2. These tests must demonstrate that the long-term flow capacity under anticipated field loads and in contact with the types of materials expected at the site is adequate to meet regulatory requirements. Thus if a fabric-covered drainage grid will be in contact with soil on one side and a flexible synthetic membrane on the other side, tests should be performed with these materials in contact with the drainage grid under anticipated maximum field loading. Considerations should also be given to creep of synthetic materials and reduction of transmissivity over time.

3.2.3 Fabric Physical Requirements

Based on the experimental work by Calhoun (1972) and subsequent field experience, the U. S. Army Corps of Engineers (Department of the Army, 1977) guide specification for filter fabric specifies strength values for use of fabric in both erosion control and subsurface drainage/filtration applications. The requirements for subsurface drainage require a tensile strength (grab method) of 445 N (100 lb), puncture strength of 178 N (40 lb) (ASTM D 3787 modified as described in Chapter 2), and an abrasion resistance of 100 N (22-1/2 lb) (ASTM Method D 3884). Bell and Hicks (1983) propose minimum mechanical properties for fabric as follows: minimum tensile strength, 334 N (75 lb) (ASTM 1682, grab method); minimum failure elongation, 20 percent (strain from ASTM D 1682), and minimum tear resistance, 222 N (50 lb) (trapezoidal tear, ASTM D 1117).

Haliburton et al. (1981) proposed strength values similar to those recommended by the U. S. Army Corps of Engineers, with the addition of a burst strength requirement of 1,379 kPa (200 psi) and a reduction of puncture strength to 156 N (35 lb) and abrasion resistance to 89 N (20 lb).

The recommended minimum physical requirements for fabrics used in filtration and drainage applications are given in Table 3-1. The values given are based on a consensus of the recommendations given above.

3.2.4 Environmental Resistance Requirements

General environmental resistance requirements for fabrics to be used in filtration and drainage applications are given in Table 3-1. Requirements for chemical resistance will be highly site-specific. Fabrics used in the cover layers of a solid waste landfill will not be subjected to any more than normal soil organisms and chemicals, but fabrics used in leachate collection systems or interceptor trenches may be subjected to high concentrations of chemicals. Compatibility tests are recommended on a site-specific basis using candidate fabrics to determine suitability. In addition to any site-specific chemical resistance requirements, any geotextile made from polymers other than polypropylene, polyester or polyvinylidene-chloride should meet the general environmental resistance requirements in Table 3-2.

3.3 Use of Fabric in Subsurface Drains

3.3.1 Fabric Selection Criteria

The fabric selection criteria for underdrains, interceptor drains, and drainage blankets are essentially the same. While the filtration and strength requirements would remain the same for each, the requirement for in-plane flow capacity would depend on whether the fabric or composite were being used as a drain as well as filter for the surrounding material. As stated previously, the chemical resistance requirements depend on site-specific factors as well as the type of application.

3.3.2 Interceptor Drain and Collector Drain Construction Procedures

Interceptor drains are normally placed at three locations in waste containment facilities. They may be placed around the periphery of a waste site to intercept ground water and prevent its entering a contaminated area. Interceptor drains may be built into a seepage cutoff wall to intercept leachate or contaminated ground water and prevent its buildup within the site, and they may be placed in a slope to intercept seepage and prevent its exiting at the surface in an uncontrolled manner and causing saturated unstable conditions. Collector drains are built as part of a leachate collection system to speed the flow of leachate to a central sump area or as part of a multilayered cover system to collect and discharge rainwater that has infiltrated the top soil layer.

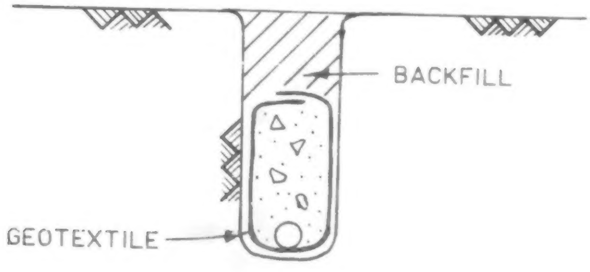
Computation of expected inflow volumes, drain size, outlet pipe spacing, location of trench, and other hydraulic parameters are beyond the scope of this manual.

The configuration of a typical collector trench, interceptor trench, and side-slope seepage cutoff trench is illustrated in Figure 3-2. In each of these cases, the fabric is selected to protect the surrounding soil, and the granular material placed in the trench should preferably be open-graded high-permeability drainage material to facilitate drainage. The high-permeability of open-graded drainage material may allow a considerable reduction in the physical dimensions of the underdrain and may eliminate the need for a collector pipe for drainage distances on the order of 9 to 30 m (30 to 100 ft) according to Steward et al. (1977).

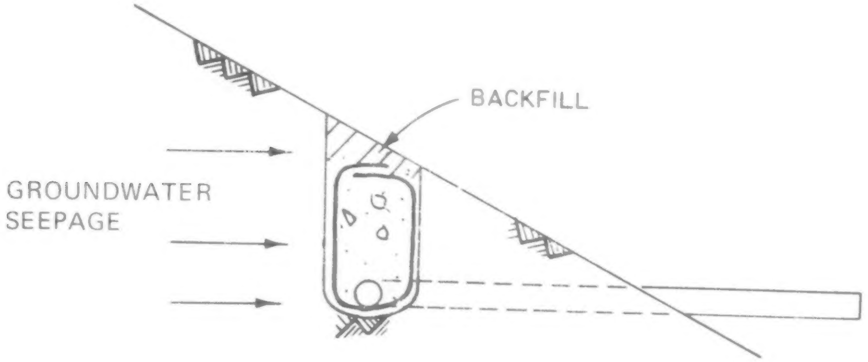
The practice of wrapping drain pipe in fabric and using a drainage sand to protect the surrounding soil is not a preferred practice and should be avoided. This practice reduces the surface area through which seepage takes place through the filter fabric, thus exacerbating any reduction in permeability that may occur in the drainage system. When fine drainage material is used in the trench, the benefits of high-flow capacity are to a great extent lost, as fine drainage material such as concrete sand is much less permeable than open-graded gravel. Finally, wrapping collector pipes may make drainage

FIGURE 3-2

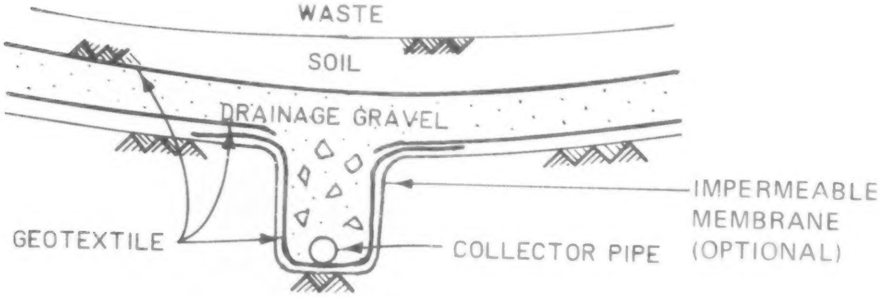
INTERCEPTOR AND COLLECTOR TRENCH CONFIGURATIONS


BACKFILL
GEOTEXTILE

a. GROUND WATER OR LEACHATE INTERCEPTOR TRENCH


BACKFILL
GROUNDWATER
SEEPAGE

b. GROUND WATER SEEPAGE INTERCEPTOR TRENCH


WASTE
SOIL
DRAINAGE GRAVEL
IMPERMEABLE
MEMBRANE
(OPTIONAL)
GEOTEXTILE
COLLECTOR PIPE

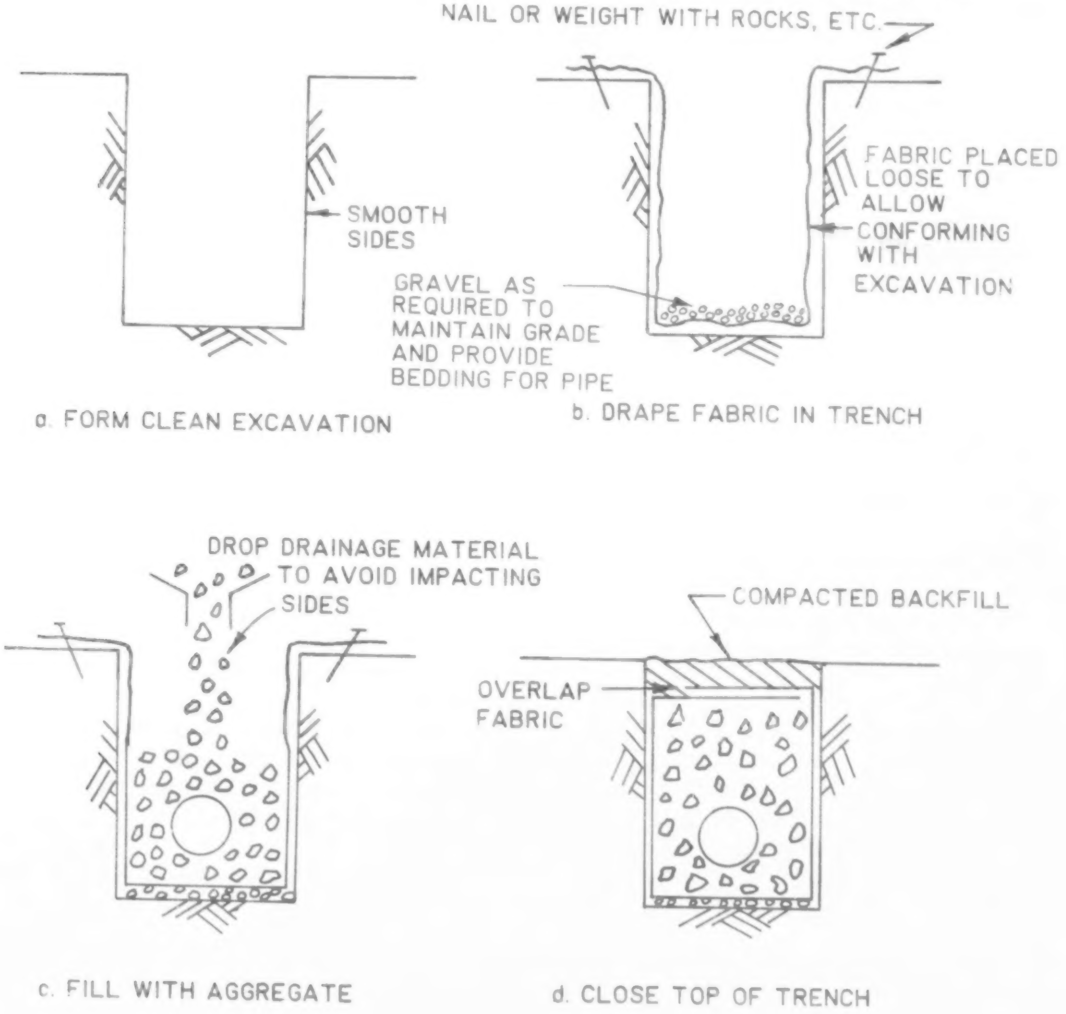
c. COLLECTOR TRENCH AS PART OF LEACHATE COLLECTION SYSTEM

system maintenance such as high-pressure-back flushing impossible because of the possibility of damaging the fabric from a direct high-pressure jet. The experiences of several authors substantiate the recommendation for avoiding the practice of wrapping the collector pipe with fabric (Haliburton et al. 1981; Wolf and Christopher, 1982).

The construction procedure for lining an interceptor drain is illustrated in Figure 3-3. For collector drains in leachate collection systems, the procedure is essentially the same except that the fabric, instead of being folded over as shown in Figure 3-3d, is fixed in the open, laid-back position. Fabric installed as part of the leachate collection blanket is lapped over this fabric at least 0.3 m (12 in.), and drainage material is placed to grade over the trench and the surrounding area.

FIGURE 3-3

GENERAL CONSTRUCTION PROCEDURE FOR INTERCEPTOR TRENCH DRAINS


NAIL OR WEIGHT WITH ROCKS, ETC.
SMOOTH SIDES
FABRIC PLACED LOOSE TO ALLOW CONFORMING WITH EXCAVATION
GRAVEL AS REQUIRED TO MAINTAIN GRADE AND PROVIDE BEDDING FOR PIPE
DROP DRAINAGE MATERIAL TO AVOID IMPACTING SIDES
COMPACTED BACKFILL
OVERLAP FABRIC

a. FORM CLEAN EXCAVATION

b. DRAPE FABRIC IN TRENCH

c. FILL WITH AGGREGATE

d. CLOSE TOP OF TRENCH

3.3.3 Drainage Blanket Construction Procedures

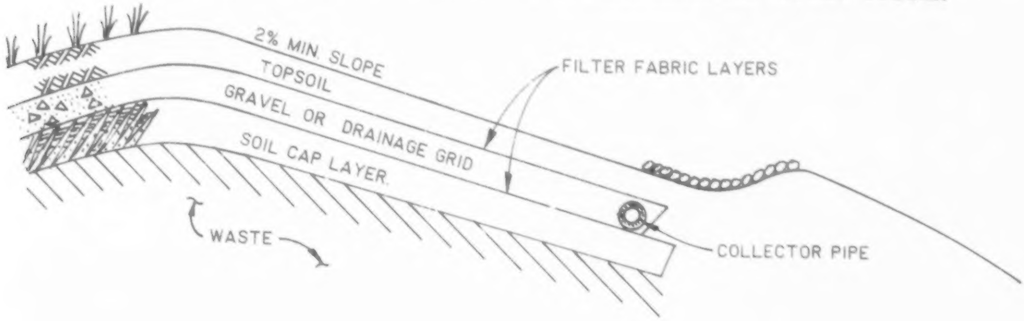
Drainage blankets are encountered in land waste disposal operations either in leachate detection/collection systems or as a drainage layer in multilayered cover systems. In either case, engineering fabric is used to envelop the drainage layer and prevent surrounding waste solids or soil from infiltrating and destroying the flow capacity of the drainage layer.

The placement of filter fabric in the construction of leachate collection is relatively straightforward. The fabric is unrolled over the surface to be covered and the seams are completed by either field sewing or by overlapping a minimum of 0.3 m (12 in.). The configuration of a multilayered cover system in which fabric is used as a filter is shown in Figure 3-4.

In some instances it is necessary to place a drainage layer on a relatively steep slope. In these applications, it will normally be necessary to weigh the fabric at the top of the slope and stake the fabric at intervals along the slope to prevent slippage and wind lift.

FIGURE 3-4

USE OF FABRIC FOR FILTRATION IN A MULTILAYERED COVER SYSTEM



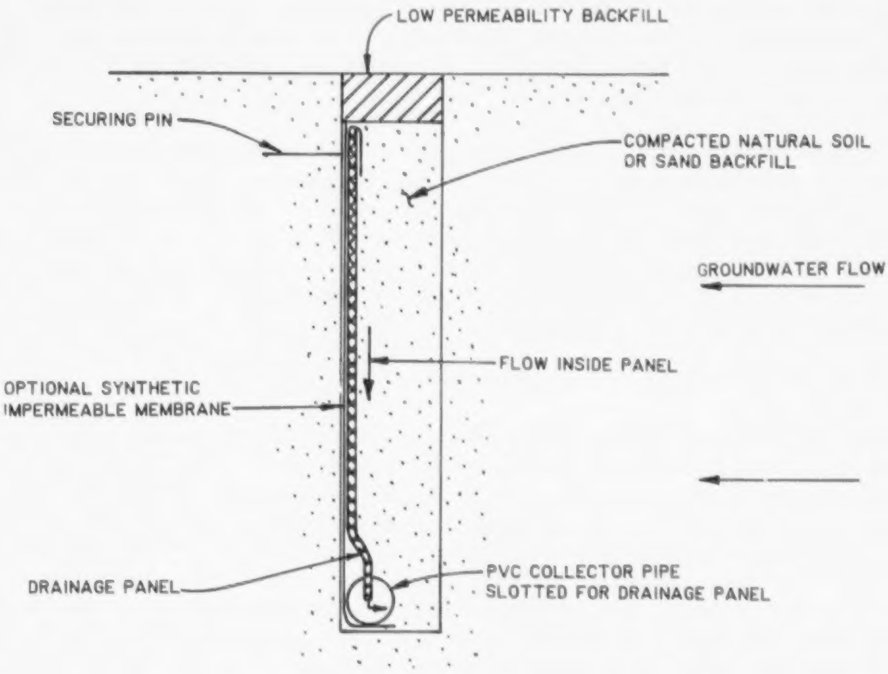
3.3.4 Prefabricated Drainage Systems

As described in Chapter 1, a number of recently marketed products have the capability to provide both filtration and drainage without the need for use of drainage aggregate. The products are variously known as prefabricated fin drains or prefabricated drainage systems. Examples of such systems appear in Figures 3-5 and 3-6. When these drainage systems are used as interceptor trenches, an impermeable synthetic liner can be attached to one side of the panel during manufacture, providing an added barrier against ground-water/contaminant leachate movement. When used against retaining walls, these systems provide the drainage necessary to prevent possible tipping or failure of the wall as a result of the buildup of hydrostatic pressure against the wall. The prefabricated drainage panels substitute for a granular drainage aggregate layer that would ordinarily be required against the wall to prevent such pressure buildup.

In the design of a subsurface drainage system using prefabricated drainage panels, the filtration properties of the panel's outer layers must fulfill

FIGURE 3-5

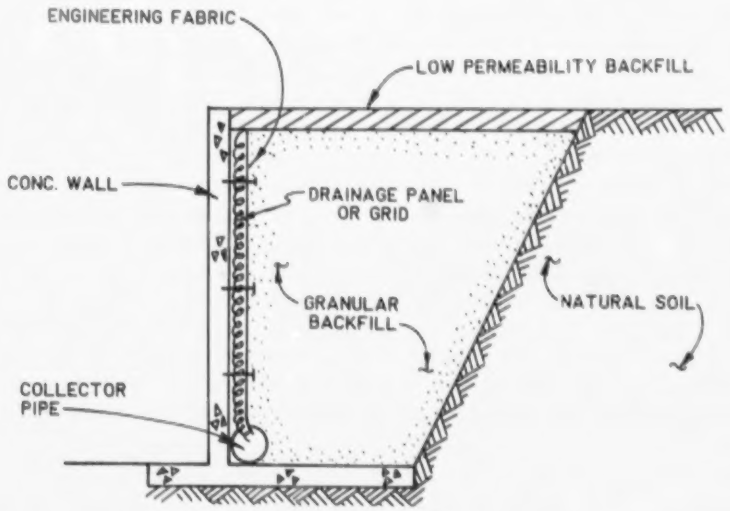
PREFABRICATED DRAINAGE PANEL INTERCEPTOR/CUTOFF TRENCH DRAIN



LOW PERMEABILITY BACKFILL
SECURING PIN
COMPACTED NATURAL SOIL OR SAND BACKFILL
GROUNDWATER FLOW
FLOW INSIDE PANEL
OPTIONAL SYNTHETIC IMPERMEABLE MEMBRANE
DRAINAGE PANEL
PVC COLLECTOR PIPE SLOTTED FOR DRAINAGE PANEL

FIGURE 3-6

PREFABRICATED DRAINAGE PANEL TO RELIEVE HYDROSTATIC PRESSURE AGAINST RETAINING WALL



ENGINEERING FABRIC
LOW PERMEABILITY BACKFILL
CONC. WALL
DRAINAGE PANEL OR GRID
GRANULAR BACKFILL
NATURAL SOIL
COLLECTOR PIPE

the same criteria as required for other filtration/drainage applications. The potential volumes of water or leachate that must be handled by the drainage system must be determined and compared with the flow capacity of the type of prefabricated drainage system under consideration. The accumulated volume of water or leachate carried to the discharge pipe cannot exceed the prefabricated drainage systems flow capacity or the flow capacity of the collector pipe, whichever is smaller.

The flow capacities of drainage panels and grids are dependent on the magnitude of the normal stress applied to them under long-term loading. Therefore the designer must calculate the highest level of stress expected on the panel and must have test data verifying the particular drainage system's ability to maintain adequate flow rates under long-term stressing at the calculated normal pressures. Details of drainage panel collector pipe connections are shown in Figure 3-7.

3.3.5 Strip Drains - Case History

Strip drains are inserted by means of special equipment into soft sediments to accelerate the consolidation of these materials. The theoretical treatment of strip drains for consolidation is similar to the theoretical analysis for sand drains and is amply treated in the literature. See, for example, Kjellmann (1948), Risseeuw and van den Elzen (1977), Hansbo (1981), and McGown and Hughes (1981). Normally, strip drains are inserted vertically. However, strip drains might be installed horizontally in soft sediment containment areas to accelerate the consolidation of such sediments by providing intermediate drainage layers while additional material is being deposited. Though to our knowledge this has not been tried at a waste disposal site, a similar application proved feasible for a coal refuse embankment (Thacker and Schad, 1983).

In the mining and power industries, cohesive soil and/or cohesive wastes are used to construct dams to retain a variety of wastes. As with any embankment composed of cohesive material, high pore-water pressures created during construction can lead to instability and failure of the embankment if not controlled. The embankment and the fine sediments behind the embankment are often placed built in stages, allowing excess pressures to dissipate between construction stages. Or, as in the case of one coal refuse disposal site in eastern Kentucky, pore-pressure dissipation was accelerated by installation of strip drains. The layout of the strip drains is shown in Figure 3-8. Figure 3-9 shows the increased rate of pore-pressure dissipation for the embankment in which the strip drains were installed. Beyond the advantages of expediting construction of the embankment and accelerating drainage of soft waste sediments behind the dam, the increased rate of consolidation allows faster placement of waste material. This last advantage applies to waste ponds where the ongoing deposition of waste requires that the wastes already placed be consolidated as rapidly as possible to allow room for additional waste.

FIGURE 3-7

EXAMPLES OF DRAINAGE PANEL COLLECTOR PIPE CONNECTIONS (Hunt, 1982)

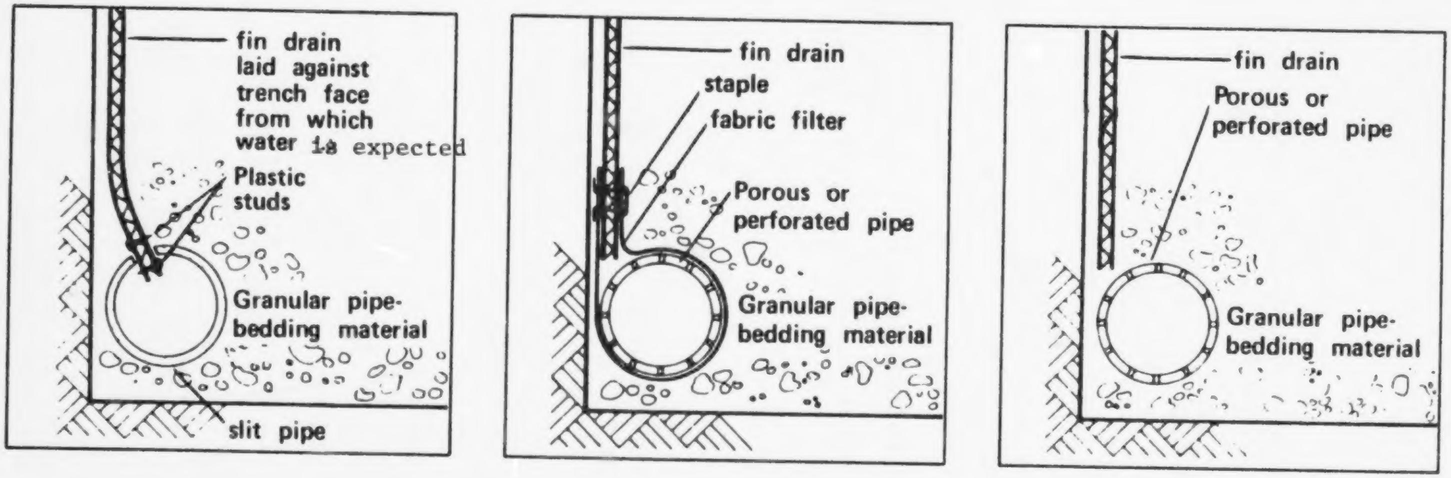

fin drain
laid against
trench face
from which
water is expected
Plastic
studs
Granular pipe-
bedding material
slit pipe
fin drain
staple
fabric filter
Porous or
perforated pipe
Granular pipe-
bedding material
fin drain
Porous or
perforated pipe
Granular pipe-
bedding material

FIGURE 3-8

LOCATION OF HORIZONTALLY PLACED STRIP DRAINS IN COAL REFUSE EMBANKMENT (Thacker and Schad, 1983)

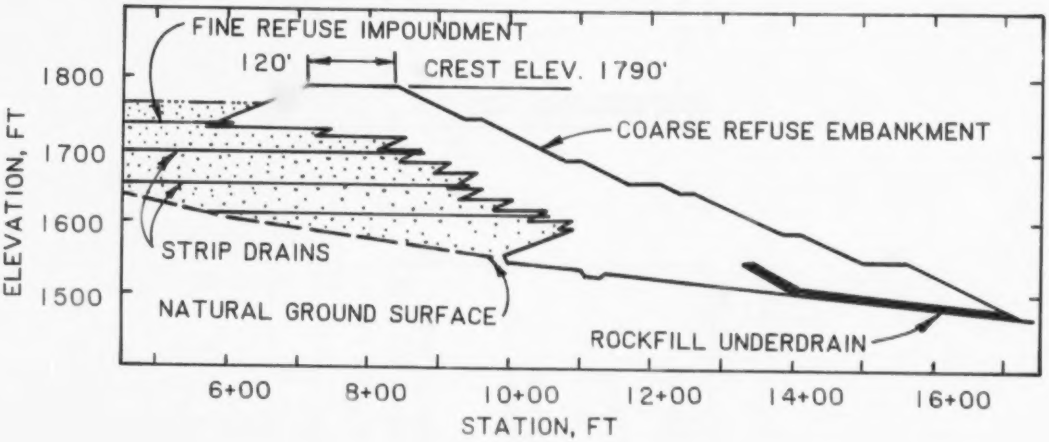
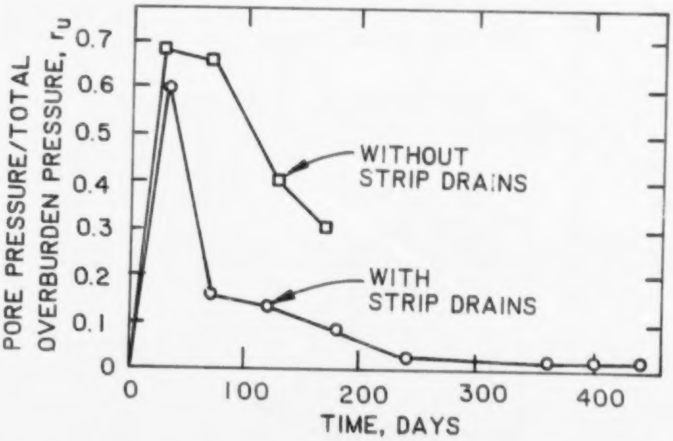

FINE REFUSE IMPOUNDMENT
120'
CREST ELEV. 1790'
COARSE REFUSE EMBANKMENT
STRIP DRAINS
NATURAL GROUND SURFACE
ROCKFILL UNDERDRAIN
ELEVATION, FT
1800
1700
1600
1500
6+00
8+00
10+00
12+00
14+00
16+00
STATION, FT

FIGURE 3-9

MEASURED RELATIONSHIPS BETWEEN TIME AND DEGREE OF PORE PRESSURE DISSIPATION WITHIN FINE REFUSE DEPOSITS WITH AND WITHOUT SYNTHETIC STRIP DRAINS (Thacker and Schad, 1983)



4.0 GAS VENTING

4.1 Introduction

When a liquid impoundment is constructed using synthetic membrane liners, an important design and construction consideration is prevention of ballooning of the membrane from gases formed beneath it. These gases most commonly result from decomposition of organic matter in the soil beneath the impoundment, but these may result from such other factors as acid leaking through holes in the membrane liner and reacting with soil minerals and evolving gases.

The use of thick fabrics with significant in-plane permeability as a venting layer between the subgrade soil and the synthetic liner has been practiced for over a decade (Giroud, 1982). These fabrics also often provide some puncture protection for the liner and a clean work surface for liner seaming during installation.

If gases generated within landfills by decomposition of organic matter or volatilization of chemicals are not dissipated in a controlled manner, several problems could occur in the cover system. Methane and other gases could, under sufficient pressure, find pathways through a clay cap, killing the vegetative cover near the leak and possibly causing dangerous concentrations of explosive and poisonous gases. If a synthetic membrane is used as part of a cover system, pressure buildup beneath the membrane could cause the gas to migrate around the periphery of the landfill, producing dangerous concentrations at unexpected locations such as the basements of nearby buildings. Thus a safe and controlled means of venting these gases must be provided in landfills where gas generation is possible. Thick fabric grids or meshes having sufficient gas transmissivity can provide the same controlled venting of gases at solid waste landfills as they do beneath liquid impoundments.

4.2 Current Practice

According to Giroud and Bonaparte (1984) there are no design procedures available for gas drainage systems. However, through trial and error, suitable materials and procedures for construction of gas drainage systems have been developed. The materials suitable for use in these systems have been categorized by Giroud and Bonaparte as:

a. Needle-punched, nonwoven fabrics having thicknesses from 2 to 5 mm (80 to 200 mils) or more

b. Mats 10 to 20 mm (3/8 to 3/4 in.) thick

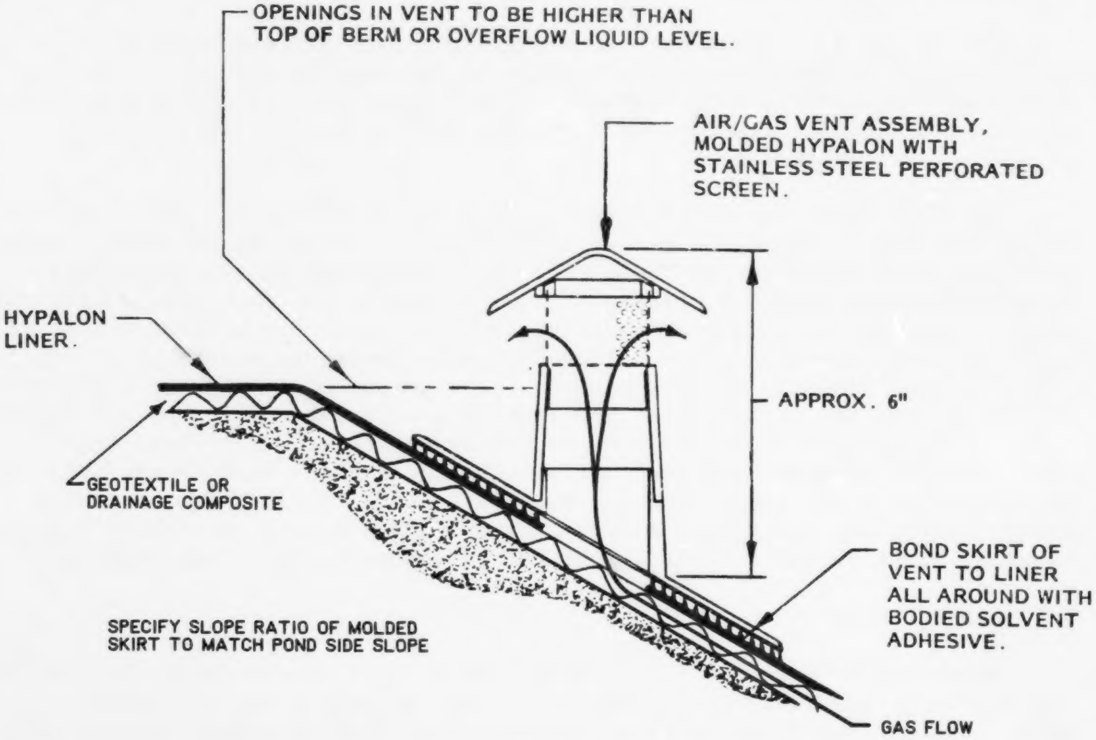
c. Nets or grids approximately 5 mm (1/4 in.) thick

d. Corrugated, waffled, or other plates covered with fabric 10 to 20 mm (3/8 to 3/4 in.) thick.

According to Kays (1977), if gas evolution is anticipated for an uncovered pond or liquid impoundment, the bottom slope of the impoundment should be about 3 percent, and a continuous pervious underdrain should cover all bottom and side slopes. Gas vents should be placed high on the side slopes just below the top of the berm. The vent spacing may vary, but a spacing of 15 m (50 ft) is recommended. Examples of typical vent designs are shown in Figures 4-1 and 4-2. These vents can be used with a conventional sand undrain or a geotextile drain.

FIGURE 4-1

MOLDED HYPALON[a] AIR/GAS VENT ASSEMBLY (Burke Rubber Company, n.d.)


OPENINGS IN VENT TO BE HIGHER THAN TOP OF BERM OR OVERFLOW LIQUID LEVEL.
AIR/GAS VENT ASSEMBLY, MOLDED HYPALON WITH STAINLESS STEEL PERFORATED SCREEN.
HYPALON LINER.
APPROX. 6"
GEOTEXTILE OR DRAINAGE COMPOSITE
BOND SKIRT OF VENT TO LINER ALL AROUND WITH BODIED SOLVENT ADHESIVE.
SPECIFY SLOPE RATIO OF MOLDED SKIRT TO MATCH POND SIDE SLOPE
GAS FLOW

---

[a] Hypalon is a registered trademark of Du Pont for chlorosulfonated polyethylene.

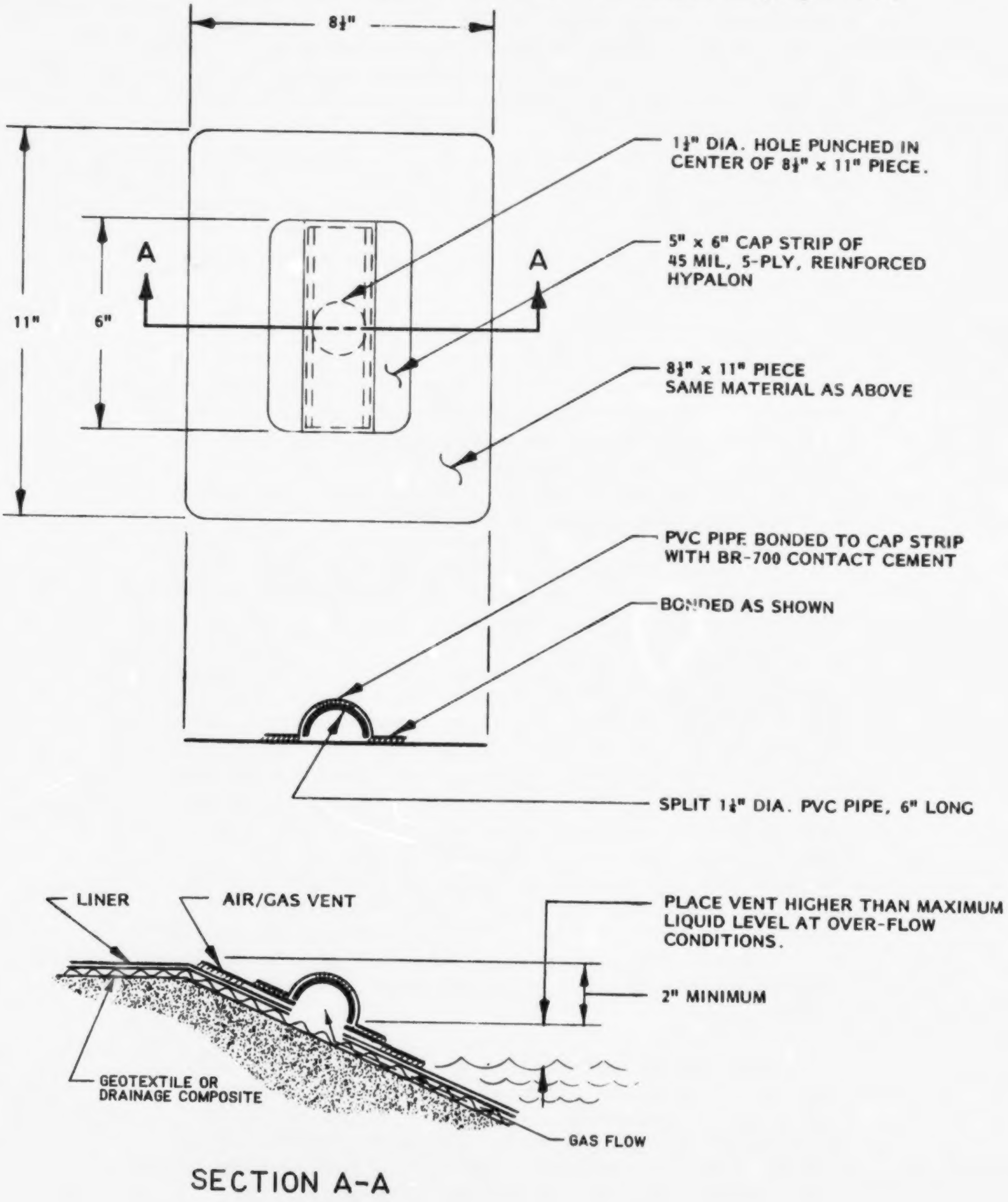
4.3 Fabric for Venting Beneath Liquid Impoundments

4.3.1 Case History 1

As an example of how synthetic materials may be used for gas venting in a liquid impoundment, Giroud and Bonaparte (1984) provide the following account:

FIGURE 4-2

HALF-TUBE AIR/GAS VENT ASSEMBLY (Burke Rubber Company, n.d.)


8½"
11"
6"
A
A
1½" DIA. HOLE PUNCHED IN CENTER OF 8½" x 11" PIECE.
5" x 6" CAP STRIP OF 45 MIL, 5-PLY, REINFORCED HYPALON
8½" x 11" PIECE SAME MATERIAL AS ABOVE
PVC PIPE BONDED TO CAP STRIP WITH BR-700 CONTACT CEMENT
BONDED AS SHOWN
SPLIT 1¼" DIA. PVC PIPE, 6" LONG
LINER
AIR/GAS VENT
PLACE VENT HIGHER THAN MAXIMUM LIQUID LEVEL AT OVER-FLOW CONDITIONS.
2" MINIMUM
GEOTEXTILE OR DRAINAGE COMPOSITE
GAS FLOW
SECTION A-A

A plastic net has been used to drain air entrapped beneath the geomembrane lining a large evaporating pond 400 by 235 m (1300 by 770 ft), containing uranium mine tailings and sulfuric acid. From past experience in the area, it was feared that air entrapped beneath the geomembrane during its installation would be pushed towards a high point of the pond bottom by the pressure of the liquid during the first filling, thus locally uplifting the geomembrane and forming a bubble. The large size of the quasi-horizontal bottom of the pond made it impractical to eliminate all high spots. (A 100 mm (4-in.) high spot is sufficient to foster air accumulation during filling of the pond).

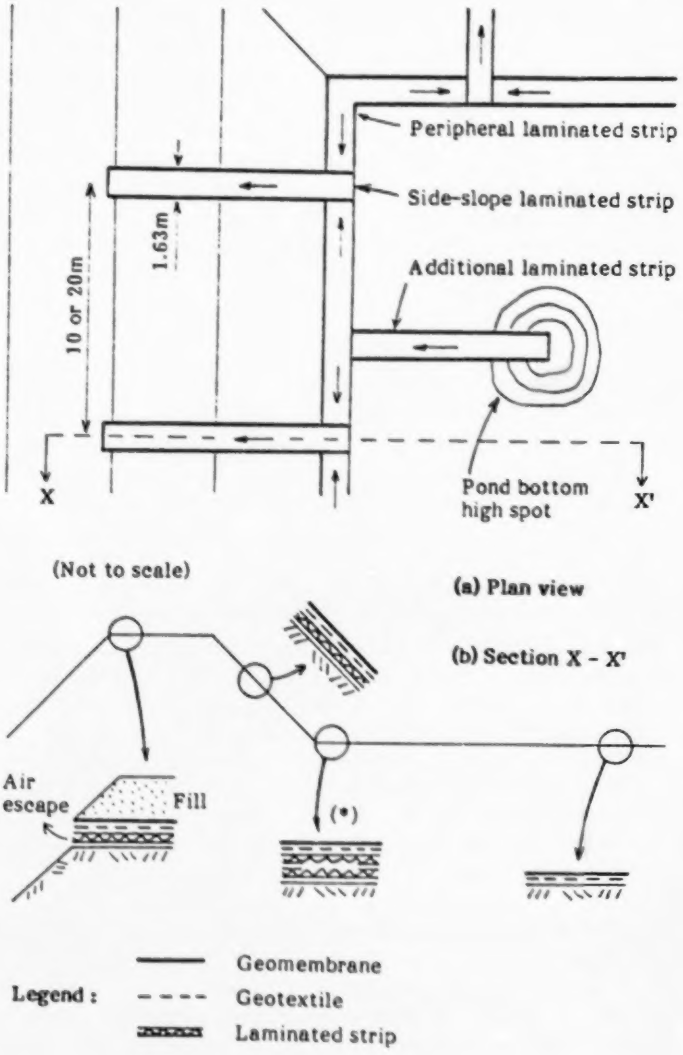
In ponds previously built in the area, plastic pipes, running every 10 m (33 ft) along the side slopes of the pond and connecting to a sand layer beneath the geomembrane, had been used for draining entrapped air. Slope deformation resulting from the properties of the locally available fill material caused some of the pipes to protrude from the slope, thereby inducing excessive concentrated stresses in the geomembranes. It was decided to use nets instead of pipes in the subsequent pond, because their flexibility would allow them to follow slope deformation without damaging the geomembrane.

Plastic net strips 1.63 m (64 in.) wide were laid out according to [Figure 4-3a]. Air is collected by a strip running at the periphery of the pond bottom and by additional strips connecting high spots of the bottom to the peripheral strip. Escape of collected air is through plastic net strips running along the side slopes of the pond and the crest of the dike. Center-to-center spacing between strips on the slopes is 20 m (60 ft) along the lower half of the pond and 10 m (30 ft) along the upper half, where more air is expected to be collected. Since no method of design is available for gas drainage, spacing has been chosen similar to the spacing of pipes used in previous ponds.

The plastic net strips on the side slopes were part of a laminated structure composed of a polyethylene low-permeability sheet, a plastic net, and a geotextile [(Figure 4-3b)]. The polyethylene sheet prevents erosion of the slope if the geomembrane leaks and liquid runs down the slope. The geotextile, placed on the plastic net, prevented it from being clogged by dust and blown sand prior to geomembrane

FIGURE 4-3

USE OF LAMINATED STRIPS FOR GAS DRAINAGE IN A GEOMEMBRANE-LINED URANIUM MINE TAILINGS EVAPORATING POND: (a) LAYOUT OF THE 1.63 m (64 in.) WIDE STRIPS; (b) CROSS SECTION.(*) CONNECTION BETWEEN PERIPHERAL STRIP AND SIDE-SLOPE STRIP (Giroud and Bonaparte, 1984)


Peripheral laminated strip
Side-slope laminated strip
1.63m
10 or 20m
Additional laminated strip
X
Pond bottom high spot
X'
(Not to scale)
(a) Plan view
(b) Section X - X'
Air escape
Fill
(*)
Legend :
Geomembrane
Geotextile
Laminated strip

placement. The laminated structures at the pond bottom are geotextile/plastic net/geotextile.

The pond was first filled in 1982 and no uplift has been observed since.

4.3.2. Case History 2

Another example of the use of engineering fabric to provide gas venting can be found in the construction of Uranium mill tailings ponds (Baldwin, 1983). In this case, the Uranium mill tailings ponds were to be constructed on lime-bearing soil. Any puncture in the membrane during use of the pond would allow the acid pond liquid to percolate into the soil, causing the generation of gas. This gas would cause the membrane to form "whales" or large uplifted sections. To combate the gas buildup in the event of a leak in the liner, a 2.8-mm- (110-mil-) thick, needle-punched fabric was installed between the membrane and the soil subgrade. Tests were performed by the fabric manufacturer to assure the owner that the fabric had sufficient gas transmissivity under expected pressures with full ponds. Any gases generated were vented to atmosphere through vents placed on 7.6-m (25-ft) centers along the top of the embankment.

4.4. Gas Venting of Landfills

A discussion of the need for and approach to gas venting is available in Remedial Action at Waste Disposal Sites, (U.S. Environmental Protection Agency, 1982). Though no rational design procedures exist for the selection of geotextiles or other drainage material for gas venting, experience has shown that the heavy-needled fabrics, grids, and mats are capable of relieving gas pressure beneath liquid impoundments and should be equally effective for releasing gas pressure beneath solid and hazardous waste covers. Where waste fill is of such permeability that gases can migrate easily within a waste fill but are prevented from moving laterally out of the fill by low-permeability soil or a synthetic membrane liner, atmospheric venting at the top of the fill may be all that is necessary to control the effects of gas generation. In this case, heavy needle-punched, nonwoven fabrics, fabric-covered grids, and fabric-covered meshes could substitute for pipe vents installed horizontally near the surface in the fill. This gas-transmitting layer would be vented to the atmosphere through risers extending from the gas-venting layer through the cover layers.

In the absence of a field-validated procedure for evaluating the effectiveness of the various drainage materials, it is recommended that one of the fabric-covered grid or mat-type products be used for gas venting. These products have substantially greater transmissivities than needle-punched, nonwoven fabrics. If a needle-punched fabric is used, it is recommended that the fabric thickness be at least 2 mm (79 mils) when compressed under a pressure equal to the anticipated weight of the cover material.

If anticipated rates of gas generation are known, transmissivity tests can be performed on the material being considered, using anticipated field loads and gas pressures to verify that gas transmissivity is adequate.

A geotextile vent layer should be located as carefully as a gravel drainage trench or blanket would be located with regard to adequate drainage of liquid away from vents and placement of drainage layers in locations of greatest gas generation.

Vents of the mushroom type (similar in configuration to that shown in Figure 4-1) or the inverted "U" shape should be satisfactory. These may be made from plastic or noncorroding metal, and there should be flanged at the lower end for stability and to distribute pressure over the venting material. When vents are used in conjunction with a synthetic membrane, special precautions must be taken to assure that the opening in the membrane is sealed around the vent pipe.

Field placement of the material types should include overlapping of ends by at least 0.3 m (12 in.) and use of multiple thicknesses of material beneath vent flanges to reduce the chance that uneven loading from the vent flange will reduce the flow capacity of the drainage material.

Peripheral vent trenches used to control lateral gas migration could be lined with geotextiles. This step prevents loss of trench effectiveness by preventing mixing of the trench drainage gravel with the finer surrounding soil. The trench could be lined with fabric (Figure 4-4) or a drainage panel (Figure 4-5). Fabric selection criteria should be the same as those given in Chapter 3 for other filtration applications.

FIGURE 4-4

GAS INTERCEPTOR TRENCH USING GEOTEXTILE TO LINE TRENCH

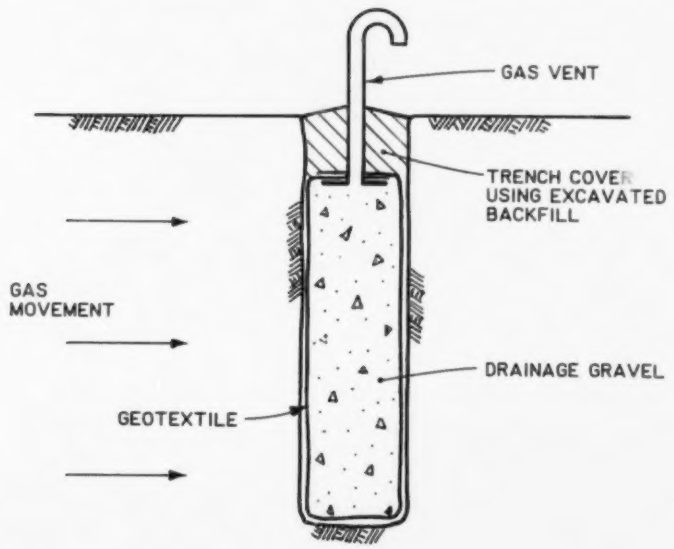
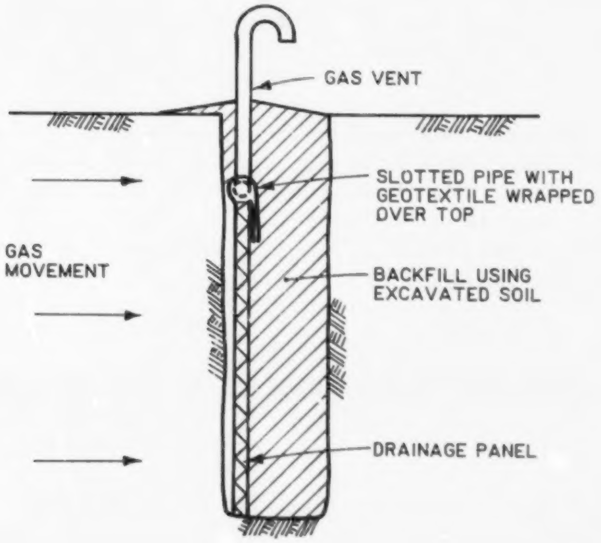


FIGURE 4-5

GAS INTERCEPTOR TRENCH USING DRAINAGE PANEL


GAS VENT
SLOTTED PIPE WITH GEOTEXTILE WRAPPED OVER TOP
GAS MOVEMENT
BACKFILL USING EXCAVATED SOIL
DRAINAGE PANEL

5.0 EROSION CONTROL

5.1 Introduction

Historically, engineering fabric design criteria and construction concepts were devised for coastal and riverbank protection. These design concepts were later extended to surface runoff and overland erosion protection. In landfill cover protection, erosion most commonly occurs in sheet form when vegetative cover is inadequate or in localized areas where rainwater runoff concentrates in surface depressions, swales, and ditches (Lutton, et al., 1982). If the soils present at a landfill are primarily silts and fine sands, erosion leads to deep gullying even when relatively flat slopes are used. One of the most serious consequences of erosion at landfills is the removal of cover soil, which leads to exposure of synthetic membrane covers with consequent deterioration from ultraviolet light exposure or mechanical damage from abrasion or vandalism.

Through efforts to stabilize streambanks, drainage ditches, and slopes with layers of stones or riprap (broken rock), it was discovered that a bedding layer of cohesionless material between the natural soil surface and the cover stone resulted in a substantial performance improvement. When properly sized with a gradation between that of the natural soil and the cover stone, the bedding layer acted as a filter, allowing seepage out of the slope and preventing the fine slope soil from eroding. It also provided support to the cover stone, preventing it from sinking into the natural slope soil.

However, to perform satisfactorily, the bedding layer for slope protection had to satisfy the granular filter criteria in Chapter 3.

In general, only finer soils of little or no cohesion (such as fine sands, silty sands, and silts) prove to have a significant erosion potential. Unless water velocities are very high, gravels are resistant to water transport, and clays usually have sufficient cohesion to resist surface erosion. The exception to this is dispersive clays.

Gibbs and Holtz (1962), in research for the U. S. Bureau of Reclamation, developed a relationship among liquid limit, plasticity index, and erosion resistance, that quantified types of low-cohesion soils subject to erosive behavior. These relationships are shown in Figures 5-1 and 5-2. Haliburton et al. (1975) investigated the erosion piping resistance for dispersive clays and found that the relationships developed by Gibbs and Holtz were not valid for dispersive clays. However, recent research by Sherard et al. (1984b) has revalidated the effectiveness of conventional granular filter criteria for retaining dispersive soils and found the conventional criteria to be adequate. Thus it seems reasonable that fabric filter criteria derived from these principles would also be valid.

FIGURE 5-1

POTENTIAL SOIL-EROSION RESISTANCE AS A FUNCTION OF DRY DENSITY AND ATTERBERG LIQUID LIMIT (Gibbs and Holtz, 1962)

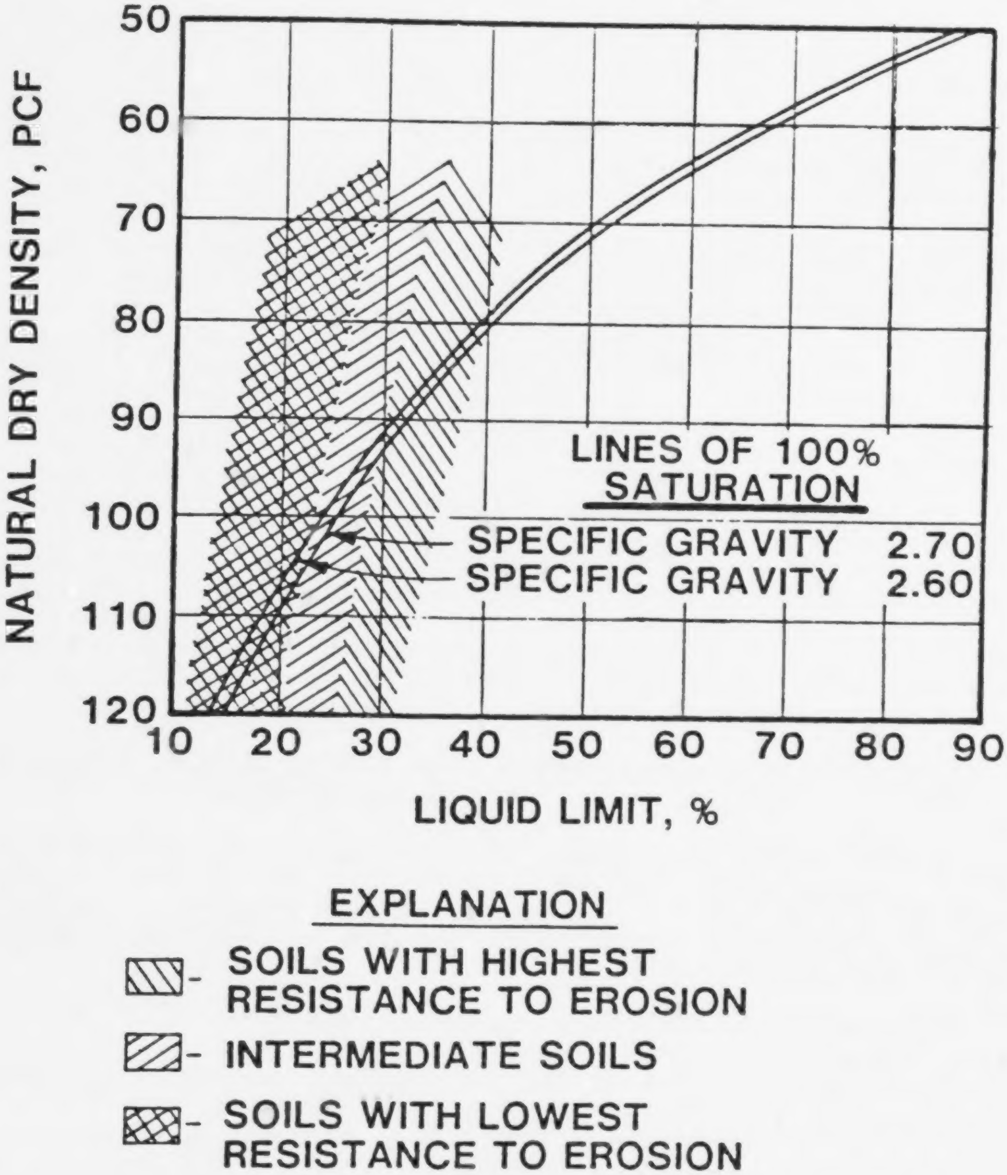
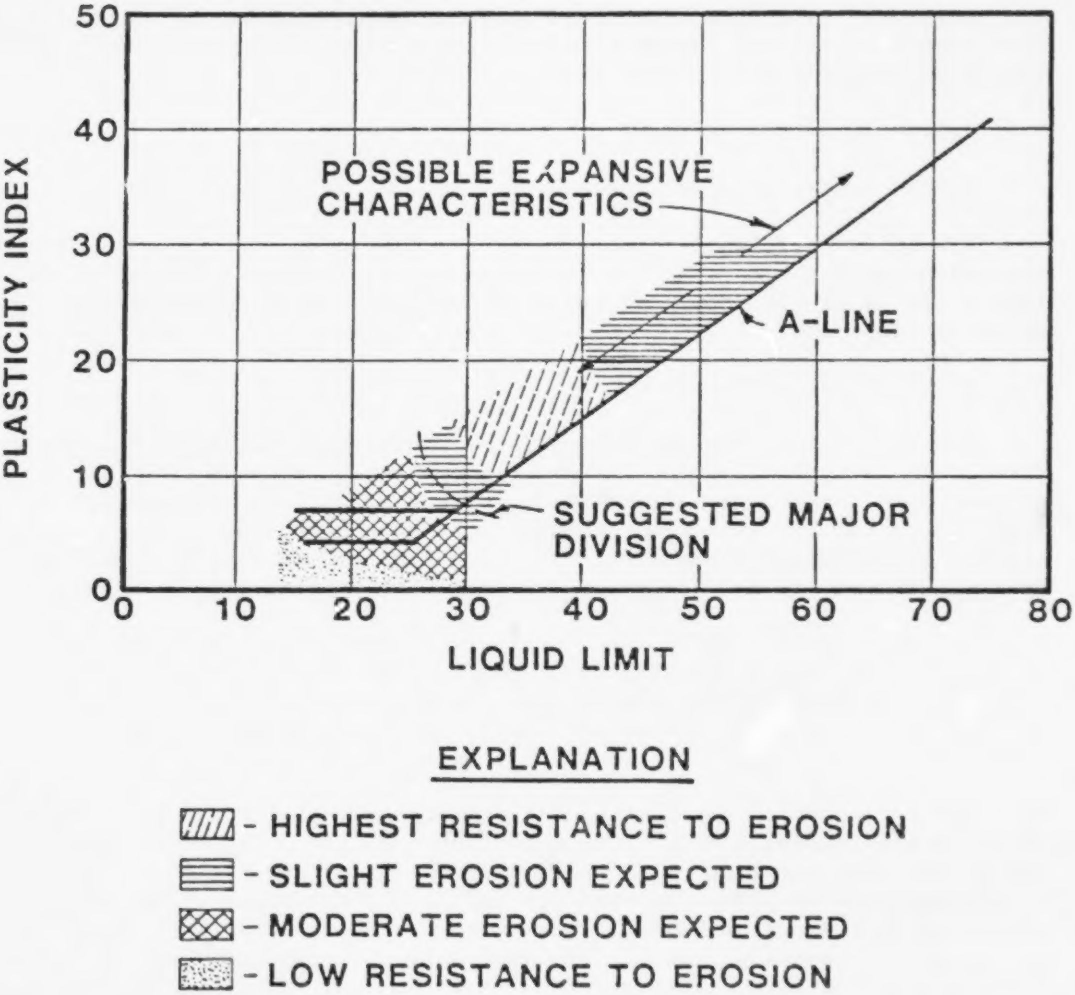


FIGURE 5-2

RELATIONSHIPS BETWEEN SOIL ATTERBERG LIMITS AND EXPECTED EROSION POTENTIAL (Gibbs and Holtz, 1962)



For the following discussion of erosion control measures using engineering fabric it is assumed that the soil has already been identified by observation, laboratory test, or other evaluation criteria to be susceptible to erosion. Methods for calculating expected flow volumes, velocities, wave heights, and other hydraulic data needed in preparation for a complete design are assumed to have been determined by other means and are not discussed in this manual. Detailed information on these parameters is available elsewhere (Department of the Army, 1970, 1971).

5.2 Fabric Selection Criteria

5.2.1 Hydraulic Requirements

Hydraulic performance requirements for fabric used in erosion control are essentially the same as the criteria used in Chapter 3 for selection of fabric for filtration applications. Recommended fabric selection criteria are given in Table 5-1.

5.2.2 Physical Requirements

The U. S. Army Corps of Engineers has developed considerable experience with the placement of protective cover stone on engineering fabric. The current U. S. Army Corps of Engineers guide specification (Department of the Army, 1977) for the selection and placement of engineering fabric in erosion control applications recognizes that the greatest stressing that engineering fabric will undergo is during installation. Their specification states:

> All fabric can be damaged if stone is dropped on it from a height greater than 0.9 m (3 ft). Some fabric can be damaged with lesser drop heights. When stone is heavy and angular it may cause punctures in fabric even if dropped from a height of 0.3 m (1 ft.).

Bell and Hicks (1983) summarize their experience with the placement of armor stone on engineering fabric by recommending that for medium-duty applications (which includes armoring to protect against wave heights up to 1.2 m, or 4 ft) a bedding layer be placed between the fabric and the armor units. They recommend that armor units not be dropped more than 0.9 m (3 ft) onto fabric protected by a bedding layer. For light-duty applications where no separate bedding layer is used, they recommend that the armor units be dropped no more than 0.6 m (2 ft).

Note that the strength requirements for fabric recommended by Bell and Hicks for erosion control are less than half the strength requirements recommended by the U. S. Army Corps of Engineers guide specification. Neither the Corps of Engineers nor Bell and Hicks place any specific limitation on the size of stone to be placed on the fabric. From the foregoing evaluations, it is recommended that the strength requirements for fabrics used for erosion control be grouped into two categories:

> Service category A includes applications in which riprap or other armor units are dropped directly on the fabric from heights no greater than 1 m (3 ft), provided that the underlying soil is sand or finer. If the underlying soil is gravelly, the armor units should not be dropped onto the fabric unless field tests are performed at the site to ascertain a maximum drop height that will preclude damage to the geotextile.
>
> Service category B includes applications in which a bedding layer is placed between the fabric and the riprap or other armor units and the armor units are dropped onto the bedding layer from heights no greater than 0.9 m (3 ft). The underlying soil shall be sand or finer. If the underlying soil is gravelly, the armor units shall not be dropped onto the fabric unless field tests are performed at the site to ascertain the maximum drop height which will preclude damage to the geotextile.

The strength requirements for each service category are given in Table 5-1. In addition to the physical requirements listed in the table, consideration should be given to the flexibility of the fabric and its coefficient of friction with respect to the underlying soil and the bedding material or armor. One should consider the possibility that the fabric will slide down the slope while it is being placed or that the bedding layer or armor will slide on the fabric, particularly on slopes steeper than 1V on 3H. Trials may have to be performed before fabric selection to establish a flexibility and/or coefficient of friction requirement for the intended application.

5.2.3 Environmental Resistance Requirements

In the typical erosion control applications in hazardous waste landfills, the environmental resistance requirements will be the same as those discussed for fabrics used for filtration applications. However, the potential for deterioration and eventual failure of the fabric from exposure to ultraviolet radiation is greater in erosion control applications where a bedding layer is not used or where the possibility exists for eventual loss of the protective cover of smaller stone or bedding material. At the present time there is not enough information to predict the long-term performance of fabrics exposed to ultraviolet radiation. However, monofilament woven fabrics should have the most resistance to degradation and should be used where extended exposures are likely.

5.3 Protection of Waste Covers, Drainage Channels, and Drainage Outlets

5.3.1 The Erosion Problem

Though it is normally desirable for aesthetic and economic reasons to vegetate landfill cover slopes and surface drainage channels wherever possible, there are nevertheless situations when vegetative cover is not adequate

TABLE 5-1

RECOMMENDED CRITERIA FOR SELECTION OF GEOTEXTILES FOR EROSION CONTROL APPLICATIONS

I. Hydraulic Requirements

A. Gap-graded soils, soils having $C_u > 20$, stratified soils, soils subjected to changing flow direction, or wave wash.

(1) Piping Resistance

EOS (in mm) $\leq D_{85}$ of soil to be protected

For soil having a D_{85} finer than the No. 70 sieve,

0.149 mm (No. 100 sieve) $\leq$ EOS (in mm) $\leq$ 0.210 (No. 70 sieve)

(2) Permeability/Clogging Resistance Requirement.

Woven fabrics: percent open area $\geq$ 10

Nonwoven fabric: Gradient ratio $\leq$ 3

B. All soils not covered by A, above.

(1) Piping Resistance

EOS (in mm) $\leq D_{85}$ of soil to be protected

For soil having a D_{85} finer than the No. 70 sieve,

0.149 mm (No. 100 sieve) $\leq$ EOS (in mm) $\leq$ 0.210 (No. 70 sieve)

(2) Permeability/Clogging Resistance

k fabric $\geq$ 10k soil

Alternate requirement (applicable to woven fabric only):

Percent open area $\geq$ 4

(continued)

TABLE 5-1 (continued)

II. Physical Requirements

Service Category A. Applications where rip-rap or other armor units are dropped directly on the fabric from heights no greater than 0.9 m (3 ft), and provided the underlying soil is sand or finer. If the underlying soil is gravelly, the armor units should not be dropped onto the fabric unless field tests are performed at the site to ascertain a maximum drop height that will preclude damage to the geotextile.

Property	Test	Minimum Value
Tensile strength	ASTM D 1682 grab test using CRE testing machine operated at 305 mm (12 in.) per minute; 25 mm (1 in.) × 50 mm (2 in.) jaws.	890 N (200 lb) in both principal directions
Failure elongation	ASTM D 1682 grab test using CRE testing machine operated at 305 mm (12 in.) per minute; 25 mm (1 in.) × 50 mm (2 in.) jaws.	20 percent in both principal directions
Tear resistance	ASTM D 1117 Trapezoidal Tear	311 N (70 lb) in both principal directions
Puncture resistance	ASTM D 3787, modified by replacing the steel ball with an 8-mm-(5/16-in.-) diameter steel rod having a hemispherical tip.	534 N (120 lb)
Flexibility and soil-fabric friction	No quantitative requirement. Fabric flexibility and friction should be considered with respect to ease of handling and ability to be placed on slope without sliding. Use ASTM D 1388 to evaluate flexibility.	

(continued)

TABLE 5-1 (continued)

II. Physical Requirements (continued)

Service Category B. Applications where a bedding layer is placed between the fabric and the rip-rap or other armor units and the armor units are dropped onto the bedding layer from heights no greater than 0.9 m (3 ft). The underlying soil shall be sand or finer. If the underlying soil is gravelly, the armor units shall not be dropped onto the fabric unless field tests are performed at the site to ascertain the maximum drop height that will preclude damage to the geotextile.

Property	Test	Minimum Value
Tensile strength	ASTM D 1682 grab test using CRE testing machine operated at 305 mm (12 in.) per minute; 25 mm × 50 mm jaws.	445 N (100 lb) in both principal directions
Failure elongation	ASTM D 1682 grab test using CRE testing machine operated at 305 mm (12 in.) per minute; 25 mm × 50 mm jaws.	20 percent in both principal directions
Tear resistance	ASTM D 1117 Trapezoidal Tear	222 N (50 lb) in both principal directions
Puncture resistance	ASTM D 3787, modified by replacing the steel ball with an 8-mm-(5/16-in.-) diameter steel rod having a hemispherical tip.	178 N (40 lb) minimum
Flexibility and soil-fabric friction	No quantitative requirement. Fabric flexibility and friction should be considered with respect to ease of handling and ability to be placed on slope without sliding. Use ASTM D 1388 to evaluate flexibility.	

III. Environmental Resistance Requirements

A. Fibers used in the manufacture of the engineering fabric shall consist of a long chain synthetic polymer consisting of at least 85 percent by weight propylene, ester, or vinylidene chloride. If any material other than those specified above are proposed, they must meet the requirements set forth in Table 3-2.

(continued)

TABLE 5-1 (continued)

III. Environmental Resistance Requirements (continued)

B. The engineering fabric shall have a composition that may include stabilizers; and shall be resistant to ultraviolet light and weathering such that it shall retain at least 90 percent of its initial tensile strength after 100-hr exposure in a Xenon Weatherometer as specified in ASTM D 4355.

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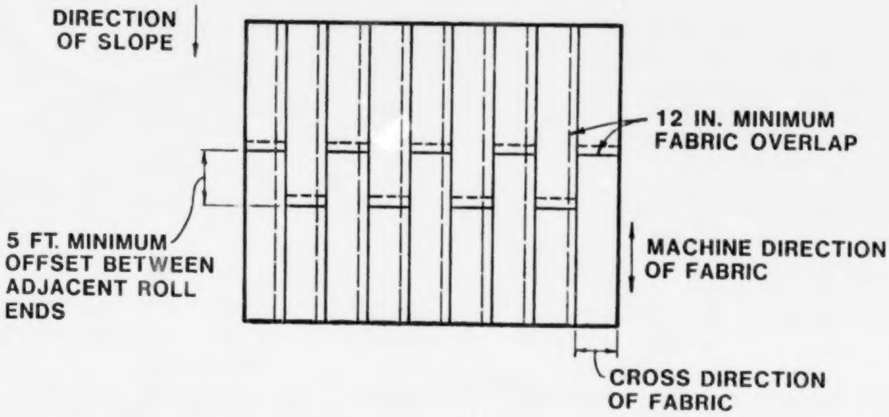
and other measures must be considered. Usually a combination of steepness of slope and poor soil and/or moisture conditions leads to inadequate vegetative protective cover and subsequent surface erosion and gulleying. Surface water runoff and runoff from intermediate drainage layers within a landfill cover must also be provided for. Where water velocities and flow volumes are high and soil is erodible, it may be necessary to provide extra erosion protection. Soils shown in Figure 5-1 to be erosion-susceptible are those for which some protection in addition to vegetative cover is needed. An alternative cover protective system is a geotextile placed over the cover soil and in turn covered by gravel, cobbles, or rock fragments to hold the fabric in place and protect it from extended exposure to ultraviolet radiation.

5.3.2 Landfill Cover Slopes

The fabric selection criteria for these applications are discussed in Section 5.2 and summarized in Table 5-1. The construction procedure for placement of fabric on landfill cover slopes consists of filling holes and depressions in the slope so that the fabric is not required to bridge depressions and be torn from lack of support when the cover materials are installed. Large stones, limbs, stumps, and other debris should also be removed before placing the fabric to reduce the chances of puncturing. The fabric should then be placed directly on the slope with the machine direction of the fabric lying up and down the slope. Adjacent fabric panels and ends of rolls should be overlapped at least 0.3 m (12 in.) with the upslope ends overlapping the downslope ends, as shown in Figure 5-3. Since overlapping can use considerable fabric, seams should be sewn whenever possible either in the factory or by portable sewing machines at the site. Sewing should be performed using polyester, polypropylene, or nylon thread, and the seam strength for both factory and field seams should equal at least 90 percent of fabric strength as tested using ASTM D 1683. Fabric may be held on the slope with steel pins before placing the cover stone, or it may be simply weighed with sandbags or rocks. Steel pins 4.8 mm (3/16 in.) in diameter by 0.46 m (18 in.) long with 38-mm- (1.5-in.-) diameter heads have proved satisfactory for anchoring fabric in relatively firm soil. Longer pins may be needed in loose soil. On steep slopes, it may be difficult to prevent slippage of the fabric on the slope and slippage of the cover material on the fabric. In instances where steep slopes are to be covered and the fabric is relatively stiff or the fabric finish is relatively slick, it is advisable to perform trials before fabric selection to

FIGURE 5-3

METHOD OF PLACING FABRIC FOR PROTECTION OF CUT AND FILL SLOPES
(Haliburton et al., 1981)


DIRECTION OF SLOPE
12 IN. MINIMUM FABRIC OVERLAP
5 FT. MINIMUM OFFSET BETWEEN ADJACENT ROLL ENDS
MACHINE DIRECTION OF FABRIC
CROSS DIRECTION OF FABRIC

determine whether the fabric will be able to be placed on the slope without sliding. Use the minimum amount of fabric anchoring necessary to keep the fabric in place before placement of the cover material. The cover stone should then be placed from the bottom of the slope upward. Experience has shown that fabric should not be pinned on slopes steeper than 1V on 3H, as the fabric will slide down the slope to some degree as the cover material is placed so that extra fabric must be allowed at the top of the slope (Couch, 1982).

Exposure of the fabric to sunlight during installation should be minimized and maximum total exposure should not exceed 30 days.

5.3.3 Drainage Channels and Culvert Outlets

If slopes are shallow enough, if the nature of the soil is nonerosive, and if the water volumes to be conveyed are small, vegetative cover is all that is needed to provide permanent erosion protection for drainage channels. These cases can use specialized fabrics designed to prevent erosion while grass or other protective vegetation is established. Such fabrics are designed to degrade after the vegetation has had time to establish itself. At least one matlike product is available that provides erosion protection while seedlings are being established, and is designed to resist environmental deterioration and serve as additional root anchoring after plant cover has established itself.

In cases where it is not desirable or feasible to establish vegetative cover for erosion protection, a layer of cobbles or rock fragments can be used to line the ditch. To prevent the rock from sinking into the soil and having the flowing water erode soil from between the rocks, a layer of fabric can be placed between the rock and soil. Selection criteria for the fabric are discussed in Section 5.2 and summarized in Table 5-1. Before installation of the fabric, the area to be covered should be smoothed, and any depressions should be filled and soft spots compacted. Large rocks, limbs, roots, and other debris should be removed before placing the fabric to prevent punctures. Fabric should be unrolled with the machine direction parallel to the alignment of the ditch. Most fabrics are wide enough that the entire width of the ditch can be covered by the width of one roll of fabric. In cases where the width of the ditch is wider than one roll, the edges of the adjacent rolls should be sewn rather than overlapped. The reason is that in most cases where two rolls are required to cover the width of a ditch or channel, the seam will fall in the center of the channel (see Figure 5-4) where erosion and undermining potential is greatest. The ends of rolls should be overlapped at least 0.9 m (3 ft), with the upstream roll overlapping the downstream roll to provide a shingling effect and retard undermining (Figure 5-5).

In cases where culverts or pipe outlets empty into drainage ditches, fabric covered with stone or concrete blocks provides scour protection against the concentrated flows at these locations. Figure 5-6 shows fabric placement for this type of application.

5.4 Streambank and Wave Protection

5.4.1 Fabric Requirements

Though placing a solid waste disposal facility adjacent to a stream, lake, or shoreline would be rejected today as unsuitable because of potential ground-water and erosion problems, many existing waste dumps are located adjacent to streams or along shore areas. Consequently, remedial action plans may require erosion protection along streambanks and shorelines. Streambank and shoreline erosion results from scouring by tractive forces of water against erodible soils and from seepage out of the streambank or shoreline slope. Seepage out of a bank or slope can result from water flow into the bank when stream levels are high, followed by flow out of the bank when water levels recede, or it can result from wave wash causing water flow into the bank during wave crests, followed by seepage out of the bank as the wave recedes. This reversing flow condition is a severe test for a geotextile's resistance to clogging. Selection of fabric with good clogging resistance is extremely important to prevent slope failure as a result of high pore pressures from flow restriction through the fabric and out of the bank. The fabric selection criteria for streambank protection applications are discussed in Section 5.2 and summarized in Table 5-1.

5.4.2 Streambank Protection Construction Procedures

The procedures given here are essentially those proposed by Keown and Dardeau (1980). The bank should be cleared of vegetation and graded to a smooth slope. Pockets of soft soil should be excavated and replaced or compacted. Rock or other debris that may cause puncturing of the fabric should be removed. The fabric should be unrolled onto the bank, with the roll length parallel to the direction of stream flow. Adjacent fabric panels should have a minimum overlap of at least 0.3 m (12 in.) along edges and at the ends of rolls. When the fabrics overlap, the upstream edge should have a minimum 1.5 m (5 ft) offset between roll ends of adjacent panels. Edges of upslope

FIGURE 5-4

PLACEMENT OF FABRIC IN SWALE AT WINDHAM, CONNECTICUT, LANDFILL (Lutton, et al., 1982)

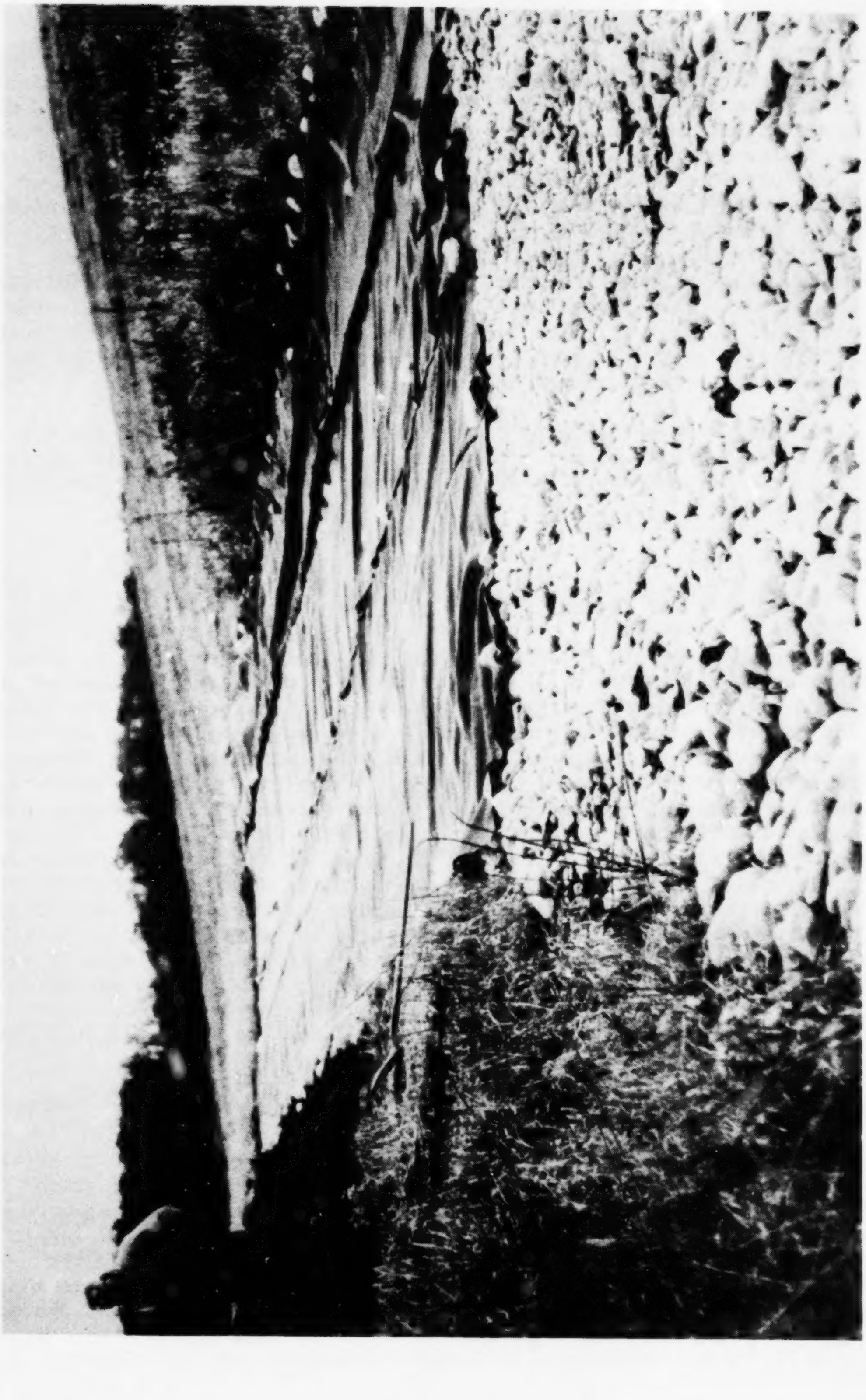
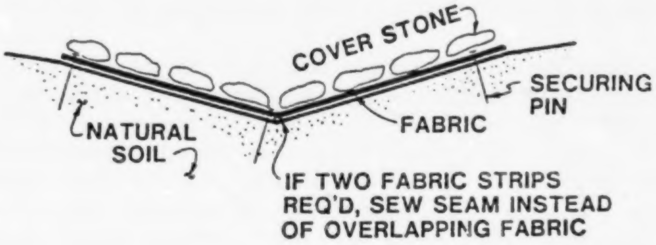
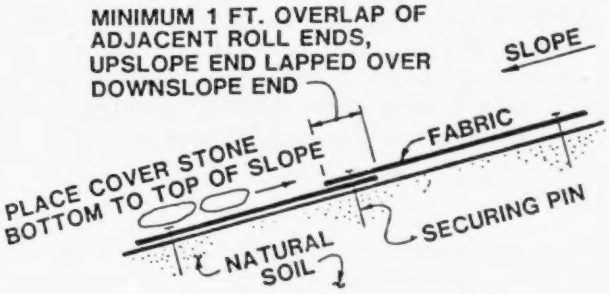


FIGURE 5-5

USE OF FABRIC IN CONSTRUCTION OF RUNOFF COLLECTION/DIVERSION DITCHES
(Haliburton, et al., 1981)


COVER STONE
SECURING PIN
FABRIC
NATURAL SOIL
IF TWO FABRIC STRIPS REQ'D, SEW SEAM INSTEAD OF OVERLAPPING FABRIC

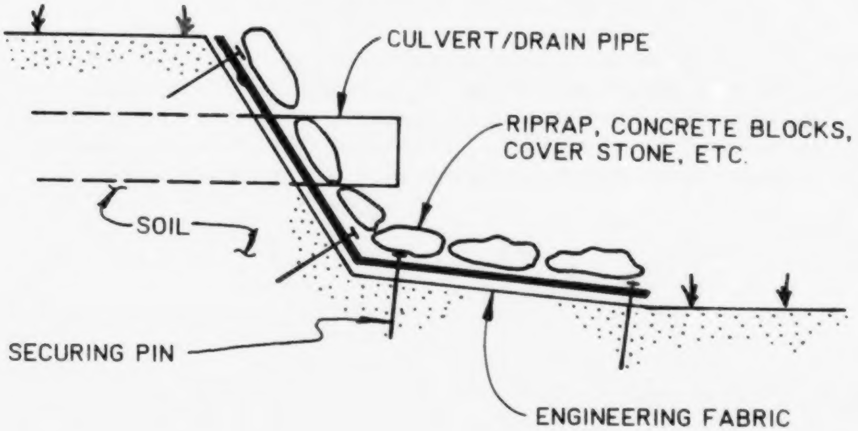
CROSS-SECTION OF FABRIC LINED-DITCH


MINIMUM 1 FT. OVERLAP OF ADJACENT ROLL ENDS, UPSLOPE END LAPPED OVER DOWNSLOPE END
SLOPE
FABRIC
PLACE COVER STONE BOTTOM TO TOP OF SLOPE
SECURING PIN
NATURAL SOIL

CENTERLINE PROFILE OF FABRIC LINED-DITCH

FIGURE 5-6

USE OF FABRIC TO PROVIDE SCOUR PROTECTION FOR CULVERT OUTLET
(Haliburton et al., 1981)


CULVERT/DRAIN PIPE
RIPRAP, CONCRETE BLOCKS, COVER STONE, ETC.
SOIL
SECURING PIN
ENGINEERING FABRIC

panels should be placed over downslope edges. The preferred arrangement of fabric panels is shown in Figure 5-7. Sewing adjacent panels is preferred to lapping to reduce fabric waste and produce a more secure connection between panels. Fabric may be held in place on the bank before placement of cover material by means of securing pins as described in Section 5.3.2.

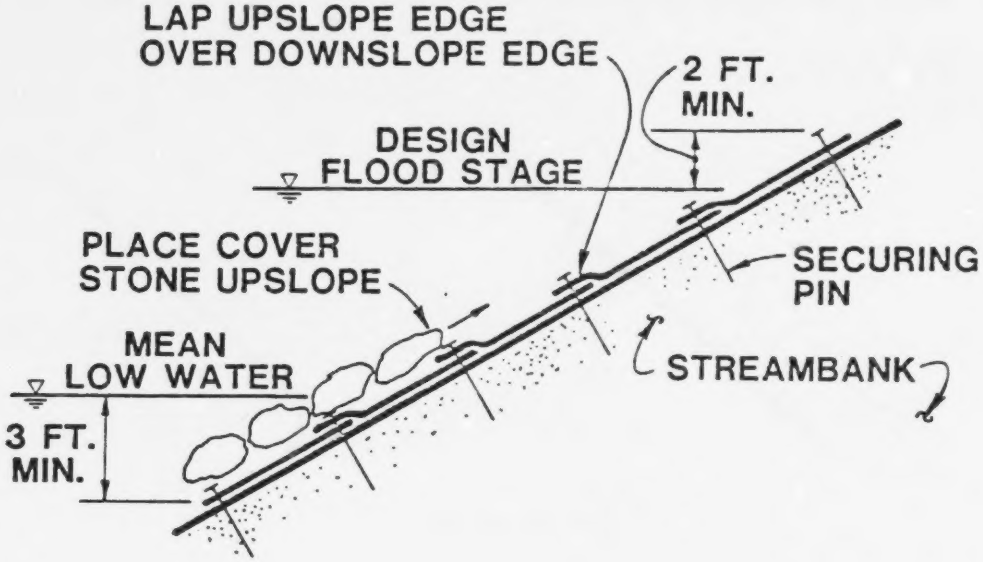
Fabric should be placed along the bank to an elevation below mean low water determined by criteria developed for other slope protection; otherwise, place fabric and cover material to a vertical distance at least 0.9 m (3 ft) below mean low water. The top of the fabric and cover material should extend to the top of the bank or to an elevation adopted for other forms of slope protection. If no other guidelines are available, fabric should be placed to an elevation 0.6 m (2 ft) above expected maximum water stage. If overtopping of the streambank is expected, or if significant overbank runoff is expected, the top edge of the fabric should be buried or otherwise keyed into the slope to prevent undermining. This should be done after placement of cover stone to prevent excessive tension in the fabric during placement. See Figure 5-8 for methods of anchoring fabric at the top of the slope. If a bedding layer is used between the armoring and fabric, the bedding must be more permeable than the underlying soil, and it must be of such a gradation as to be held in place by the armoring material. Stone should be placed from the bottom of the slope upward, rather than being dumped from the top of the slope.

5.4.3 Wave Protection

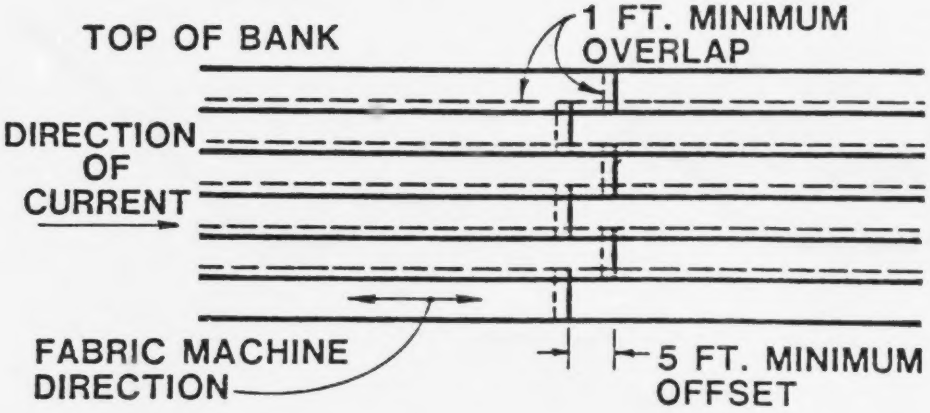
The techniques for using fabric to protect against wave action are very similar to those used for streambank protection. Just as with streambank protection, clogging of the fabric under reversing flow conditions is the greatest potential cause of poor performance. The fabric selection procedures for this application are discussed in Sections 5.1 and 5.2 and summarized in Table 5.1. In keeping with the practice of placing the long (machine) direction of the fabric in the direction of primary water movement, the fabric panels should be laid out up and down the slope. If fabric must be placed under water, 0.9 m (3 ft) overlaps at the fabric edges should be used wherever the fabric cannot be sewn before placement. If possible, fabric panels should be presewn at the factory and pulled downslope into the water. Fabric should be keyed in at both the top and bottom of the slope. Recommended treatments for top and toe of slope are illustrated in Figure 5-8. Though riprap is the most common armoring material, prefabricated blocks of various designs can be used. If prefabricated blocks are of such a design that a substantial area of the fabric is covered by the blocks, a bedding layer is recommended to facilitate drainage from the underlying soil through the openings in the blocks.

FIGURE 5-7

CROSS SECTIONS AND FABRIC PLACEMENT DETAIL FOR USE OF FABRIC IN STREAMBANK PROTECTION (Keown and Dardeau, 1980)


LAP UPSLOPE EDGE
OVER DOWNSLOPE EDGE
2 FT.
MIN.
DESIGN
FLOOD STAGE
PLACE COVER
STONE UPSLOPE
SECURING
PIN
MEAN
LOW WATER
STREAMBANK
3 FT.
MIN.

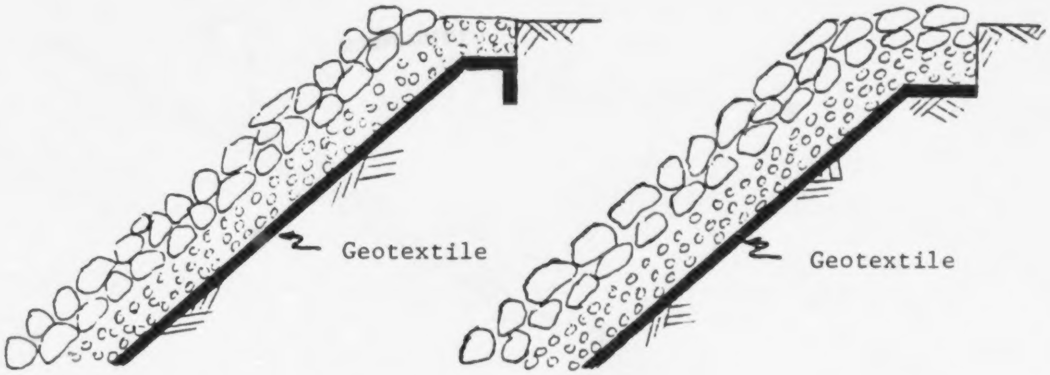
CROSS-SECTION OF STREAMBANK REVETMENT


TOP OF BANK
1 FT. MINIMUM
OVERLAP
DIRECTION
OF
CURRENT
FABRIC MACHINE
DIRECTION
5 FT. MINIMUM
OFFSET

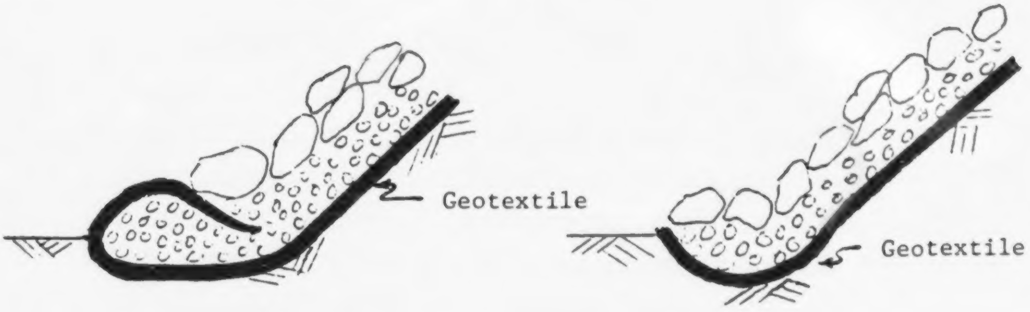
FABRIC PLACEMENT SCHEME FOR STREAMBANK PROTECTION

FIGURE 5-8

EXAMPLE ANCHORING TREATMENTS AT TOP AND TOE OF FABRIC IN WAVE PROTECTION STRUCTURES (Bell and Hicks, 1983)


Geotextile
Geotextile

Top Treatments


Geotextile
Geotextile

Toe Treatments

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APPENDIX A

ACTIVE MARKETERS OF FABRICS, STRIP DRAINS, AND DRAINAGE PANELS

DISTRIBUTORS OF GEOTEXTILES

U. S. Distributors

Advance Construction Specialties Co.
PO Box 807
Dresden, TN 38225
ATTN: Mr. H. M. Vann
Tel: (901) 364-5417

American Enka Company
Enka, NC 28728
ATTN: Mr. Carl Warren
Tel: (704) 667-7110

AMOCO Fabrics Co.
Patchogue-Plymouth Division
Civil Engineering Department
550 Interstate North, Suite 150
Atlanta, GA 30099
Tel: (404) 955-0935

Bradley Materials Company, Inc.
PO Box 254
Valparaiso, FL 32580
Tel: (904) 678-1105

Burlington Industrial Fabrics Co.
261 Madison Ave.
New York, NY 10016
ATTN: Pete Stevenson
(212) 953-1100

Carthage Mills Erosion Control Co.
124 W. 66th Street
Cincinnati, OH 45216
Tel: (513) 242-2740

Crown Zellerbach Corp.
Nonwoven Fabrics Division
PO Box 1115
Camas, WA 98607
ATTN: Tom Collins
Product Manager
Construction Fabrics
Tel: (206) 834-5954
(800) 426-0700

E. I. Du Pont de Nemours & Co., Inc.
Textile Fibers Department
Centre Road Building
Wilmington, DE 19898
ATTN: Technical Service & Marketing
Tel: (302) 774-9798
(800) 441-9475

Erosion Control Systems
Div. of Gulf States Paper Corp.
PO Box 3199
Tuscaloosa, AL 35404
Tel: (205) 553-6200

Erosion Control, Inc.
117 Canaveral Beach Blvd.
Cape Canaveral, FL
ATTN: Mr. Sivard
Tel: (305) 783-6250

Foss Manufacturing Co., Inc.
1 Whitney Avenue
PO Box 175
Haverhill, MA 01830
ATTN: Brian Jeffrey
Tel: (617) 374-0121

Griffolyn Company
Division of Reef Industries
PO Box 33248
Houston, TX 77033
Tel: (713) 943-0070
(800) 231-6074

Hoechst Fibers Industries
Division of American Hoechst Corp.
PO Box 5887
Spartanburg, SC 29304
Tel: (800) 845-7597

ICI Americas
Resale Department
Wilmington, DE 19897
ATTN: R. A. Fenimore
Tel: (302) 575-3066

Mercantile Development, Inc.
274 Riverside Avenue
Westport, CT 06880
Tel: (203) 226-7803

Mirafi, Inc.
PO Box 240967
Charlotte, NC 28224
Tel: (704) 588-4550
(800) 438-1855

Nicolon Corp.
Suite 1990, Peachtree Corners Plaza
Norcross/Atlanta, GA 30071
Tel: (404) 447-6272
(800) 241-9691

Owens-Corning Fiberglas Corp.
Technical Center
PO Box 415
Granville, OH 43023
ATTN: John Mancaster
Tel: (614) 587-0610

Phillips Fibers Corp.
PO Box 66
Greenville, SC 29602
ATTN: Engineered Products Marketing
Tel: (803) 242-6600
(800) 845-5737

Quline Corp.
560 S. Spring Court
Raleigh, NC 27658
Tel: (919) 872-7299

Staff Industries
78 Dryden Road
PO Box 759
Upper Montclair, NJ 07043
ATTN: C. E. Staff
Tel: (201) 744-5367

The TENSAR Corporation
1210 Citizens Parkway
Morrow, GA 30260
Tel: (404) 968-3255

Terrafix Erosion Control Products, Inc.
9151 Fairgrounds Road
West Palm Beach, FL 33411
Tel: (305) 793-5650
(305) 793-5727

Wayne-Tex, Inc.
901 S. Delphine Avenue
Waynesboro, VA 22980
ATTN: Frank Perkins
Tel: (703) 943-2500

West Point Pepperell, Inc.
Industrial Fabrics Division
Research Center
PO Box 398
Chawmut, AL 36876
ATTN: Bruce Helzschuh
Tel: (205) 756-7111, ext 2429

Non-U. S. Distributors

Bay Mills Midland, Limited
305 Evans Avenue
Toronto, Ontario
ATTN: Graham Tyler
Tel: (416) 252-5711

Dominion Textile, Ltd.
1950 Sherbrook St.
Montreal, Quebec
ATTN: P. Moldvar, Marketing Manager
Tel: (514) 937-5711

Enka bv
Industrial Systems-Geotechnics
Velperweg 76
Postbus 306
6800 AH Arnhem-Holland
Tel: 085-664600
Telex 45204

Low Brothers & Co. (Dundee) Ltd.
Box 54 Southward Rd.
Dundee Scotland DD19J0
ATTN: R. G. Warwick
Tel: 0382-27311

Neton Ltd.
Mill Hill, Blackburn BB2 4PJ
Great Britain
Tel: Blackburn (0254) 62431

U. S. MARKETERS OF STRIP DRAINS

Alidrain

Vibroflotation Foundation Company
United States Steel Building,
39th Floor
600 Grant Street
Pittsburgh, PA 15219
Telephone: (412) 288-7676
Contact: James Warren

Amerdrain

International Construction
Equipment, Inc.
301 Warehouse Drive
Mathews, NC 28105
Telephone: (704) 821-7681

Castle Drain Boards

Harquim International Corporation
3112 Los Feliz Boulevard
Los Angeles, CA 90039
Telephone: (213) 669-8332

Geodrain

Griffin International Drainage Corp.
100 South Broadway
Irvington, NY 15033
Telephone: (914) 591-6000
Contact: Robert Anderson

Mebra Drain

Geotechnics America, Ind.
6830 Hilo Street
Diamondhead
Bay St. Louis, MS 39520
Telephone: (601) 255-3123
Contact: Russell Joiner

U. S. MARKETERS OF PREFABRICATED DRAINAGE SYSTEMS

Eljen Drainage System

Eljen Development Corp.
15 Westwood Rd.
Storrs, CT 06268
Telephone: (203) 429-9986

Enkadrain

American Enka Co.
Enka, NC 28728
Telephone: (704) 667-7713

Hitek Prefabricated Drains

Vibroflotation Foundation Co.
United States Steel Bldg.
600 Grant St.
Pittsburgh, PA 15219
Telephone: (800) 245-1762
(412) 288-7676

Medradrain

Mirafi Inc.
PO Box 240967
Charlotte, NC 28224
Telephone: (800) 438-1855
(704) 588-4550

APPENDIX B

TEST METHODS AND STANDARDS

B.1 Introduction

This appendix lists those published test methods and standards reported in the body of this handbook (see Table B-1). Many tests are currently being developed specifically for geotextiles by ASTM Committee D 35 on Geotextiles and Related Products. Those agencies or individuals wishing to cite standardized test methods for geotextiles should contact the staff manager for Committee D 35, ASTM Headquarters, 1916 Race Street, Philadelphia, PA 19103 to ascertain the status of the many standards under development by this committee.

Detailed test procedures are given in this appendix for the fabric permeability test[a] and the percent open area[b] test, for which there are at present no published standards. Procedures are also given for the gradient ratio[b] test and equivalent opening size[b] (EOS) test. While these tests are described in the U. S. Army Corps of Engineers Guide Specification CW-02215, the procedures given here are more complete and retain the essential features described in the Guide Specification.

B.2 Suggested Test Method for Permeability and Permittivity of Geotextiles

B.2.1 Scope

This method covers a procedure for determining the hydraulic conductivity (water permeability) of geotextiles in terms of permittivity under a standard set of testing conditions.

B.2.2 Applicable Documents:

The following documents are applicable:

ASTM Standards

D 123 Definitions of Terms Relating to Textiles

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[a] This test method has been reproduced from Christopher, B. R., and Holtz, R. D., 1984, "Geotextile Engineering Manual," prepared for the Federal Highway Administration under Contract No. DTFH61-80-C-00094, Washington, D.C.

[b] This test method has been reproduced from Haliburton, T. A., Lawmaster, J. D., and McGuffey, V. C. 1981. "Use of Engineering Fabrics in Transportation-Related Applications," prepared for the Federal Highway Administration under Contract No. DTFH61-80-C-00094, Washington, D.C.

TABLE B-1
PUBLISHED TEST METHODS AND STANDARDS

Number	Date of Issuance	Title	Reference
		ASTM	Part No.[b]
D 123	84	Terminology Relating to Textiles	07.01, 07.02
C 666	84	Resistance of Concrete to Rapid Freezing and thawing	04.02
D 543	67	Resistance of Plastics to Chemical Reagents	08.01
D 572	81	Rubber Deterioration by Heat and Oxygen	09.01
D 746	79	Brittleness Temperature of Plastics and Elastomers by Impact	08.01, 09.02
D 1117	80	Nonwoven Fabrics (Trapezoidal Tear Test)	07.01
D 1388	64	Stiffness of Fabrics (Cantilever Test)	07.01
D 1435	75	Outdoor Weathering of Plastics	08.01
D 1682	64	Breaking Load and Elongation of Textile Fabrics	07.01
D 1683	81	Failure in Sewn Seams of Woven Fabrics	07.01
D 1777	64	Thickness of Textile Materials	07.01
D 2256	80	Breaking Load (Strength) and Elongation of Yarn by the Single-Strand Method	
D 2262	83	Tearing Strength of Woven Fabrics by the Tongue (Single Rip) Method (Constant Rate of Traverse Tensile Testing Machine)	07.01
D 2905	83	Number of Specimens Required to Determine the Average Quality of Textiles	07.01
D 2990	77	Tensile, Compressive, and Flexural Creep and Creep Rupture of Plastics	08.02
D 3083	76	Flexible Poly (Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining [Soil burial test]	04.04
D 3786	80a	Hydraulic Bursting Strength of Knitted Goods and Nonwoven Fabrics: Diaphragm Bursting Strength Tester Method	07.01

(continued)

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[b] 1984 Annual Book of ASTM Standards. Revision issued annually.

TABLE B-1 (continued)

Number	Date of Issuance	Title	Reference Part No.
		ASTM	
D 3787	80a	Bursting Strength of Knitted Goods: Constant-Rate-of Traverse (CRT), Ball Burst Test [Modified[c]]	07.01
D 3884	80	Abrasion Resistance of Textile Fabrics (Rotary Platform, Double Head Method)[d]	07.01
D 4354	84	Sampling Geotextiles for Testing	04.08[e]
D 4355	84	Deterioration of Geotextile from Exposure to Ultraviolet Light and Water (Xenon-Arc Type Apparatus)	04.08[e]
E 838	81	Performing Accelerated Outdoor Weathering Using Concentrated Natural Sunlight	12.02
G21	70	Resistance of Synthetic Polymeric Materials to Fungi	08.03, 14.02
G 22	76	Resistance of Plastics to Bacteria	08.03, 14.02
G 23	81	Light and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Nonmetallic Materials	07.01, 08.03, 14.02
G 26	83	Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials	08.03, 14.02
G 29	75	Algal Resistance of Plastic Films	14.02
		Department of the Army	
CW-02215	77	Plastic Filter Fabric [EOS test and Gradient Ratio Test]	[f]
CRD-C-575-60	60	Weight Change in Water	[g]

(continued)

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[c] Test procedure modified by replacing 25-mm- (1.0-in.-) diameter ball with an 8-mm- (0.31-in.-) diameter rod having a hemispherical tip.

[d] Rubber-base abrasive wheels equal to CS-17 Calibrase by Taber Instrument Co; 1 kilogram load per wheel; 1000 revolutions; determine residual breaking strength.

[e] Currently available as a separate document only; to be published in 1985 Annual Book of ASTM Standards, Part 04.08.

[f] Published by Headquarters, U. S. Army Corps of Engineers, Washington, D.C.

[g] Handbook for Concrete and Cement, Published by U. S. Army Corps of Engineers in 1949 and revised periodically.

TABLE B-1 (continued)

Number	Date of Issuance	Title	Reference
		Other	Part No.
Fed Std No. 751a	65	Stitches, Seams, and Stitchings	h
AATCC 30-1974	74	Fungicides, Evaluation on Textiles: Mildew and Rot Resistance of Textiles	i

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[h] Available from General Services Administration, Business Service Center, Washington, DC.

[i] American Association of Textile Chemists and Colorists, P.O. Box 12215, Research Triangle Park, NC 27709 [reprinted in 1982 Book of ASTM Standards, Part 32].

D 653 Definitions of Terms and Symbols Referring to Soil and Rock Mechanics

D 1776 Conditioning Textiles for Testing

B.2.3 Terminology

Terms are defined as follows:

a. Permittivity, Ψ , (T^{-1}), n.--the volumetric flow rate of water per unit cross-sectional area per unit head in the normal direction through a geotextile.

b. Geotextile--any permeable textile used with foundation, soil, rock, earth, or any other geotechnical material as an integral part of a man-made project, structure, or system.

c. Hydraulic Conductivity, k , (LT^{-1}), n.--the rate of discharge of water through a unit cross-sectional area of a porous medium under a unit hydraulic gradient and standard temperature conditions (at 20°C, or 68°F).

B.2.4 Summary of Method

This method describes a procedure for determining the permittivity of geotextiles. The constant head test is performed by maintaining a head of water on the geotextile throughout the test. The quantity of flow is measured versus time.

B.2.5 Uses and Significance

Since there are geotextiles of various thicknesses in use, to evaluate them in terms of their hydraulic conductivities (permeability coefficients) can be misleading. It is more indicative to evaluate the quantity of water that would pass through a geotextile under a given head over a given cross-sectional area. Permittivity is an expression of this; therefore it has been selected for use in this method. The use of this test method is to establish an index value by providing standard criteria and a basis for uniform reporting.

Permittivity is used to evaluate the relative permeabilities of geotextiles. Darcy's coefficient of permeability for geotextiles is difficult to establish. Darcy's coefficient of permeability as related to geotextile engineering may be computed from a permittivity value by multiplying the permittivity by the nominal thickness of the geotextile.

Note 1: To determine the coefficient of the permeability, which is an index value, the nominal thickness as determined in accordance with ASTM D 1777 should be used. It is difficult to evaluate the pressure on the geotextile during the test, thereby making it difficult to determine the thickness of the fabric under these test conditions. Fabric thickness is dimensionally insignificant in geotechnical terms.

B.2.6 Apparatus

The apparatus used in this method shall meet the following requirements: The apparatus must be capable of maintaining a constant head of water on the geotextile being tested.

In addition, the apparatus must not be the controlling agent for flow during the test. It will be necessary to establish a calibration curve of volumetric flow rate versus head for the apparatus alone in order to insure compliance with this.

The device consists of an upper and lower unit that fasten together with the geotextile specimen positioned in the bottom of the upper unit. There is a standpipe for measuring the constant head value. An adjustable discharge pipe would allow adjustment of the head of water on the specimen.

B.2.7 Sample Selection

For sample selection, use D 4354, Sampling Geotextiles for Testing, except that the number of rolls selected as samples from any individual lot shall not exceed 3, however.

B.2.8 Test Water Preparation

To insure the reproducibility of test results, the test water shall be de-aired under a vacuum of 710 mm (28 in.) of Mercury (Hg) for a period of time to bring the dissolved oxygen constant down to a maximum of 6 parts per million. The dissolved oxygen constant may be determined by either commercially available chemical kits or by a dissolved oxygen meter.

Allow the de-aired water to stand in a closed storage tank under a slight vacuum until the water reaches room temperature.

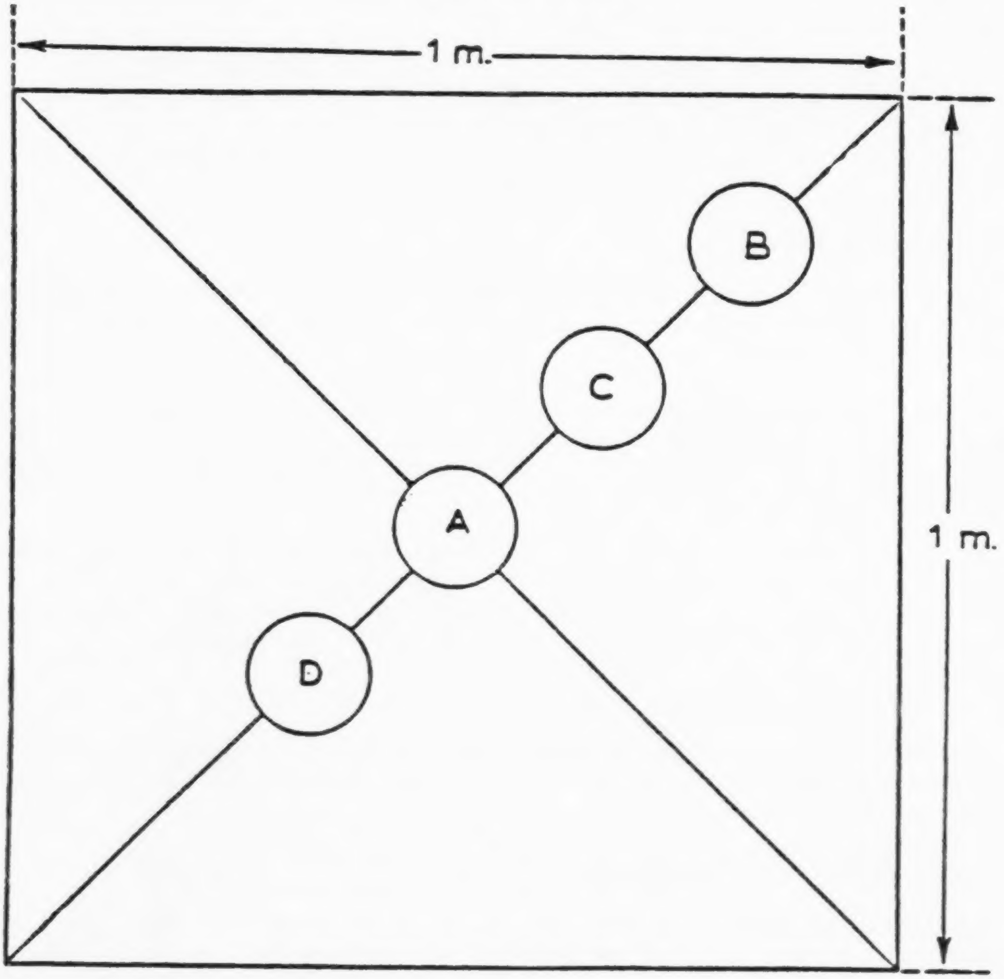
B.2.9 Specimen Preparation

To obtain a representative value of permittivity, four specimens are to be obtained from each 1-m^2 sample.

Refer to Figure B-1 and select the specimens as follows:

FIGURE B-1

SPECIMEN PATTERN



Specimen A is taken at the center of the sample. Specimen B is to be taken at one corner (center located 200 mm, or 8 in., from the corner). Specimen C is taken midway between A, B, and D, an equal distance from A and C, and located on the line with A, B, and C. Specimens shall be cut to fit testing apparatus.

Place the specimen in the test apparatus selected for use.

Specimen conditioning will be accomplished by soaking the specimen rings, with specimen attached, in a closed container of de-aired water at room conditions for a period of 2 hr.

B.2.10 Suggested Constant Head Procedure

Assemble the apparatus with the specimen in place.

Backfill the system through the standpipe or discharge pipe, with de-aired water. Backfilling in this manner forces any trapped air out of the system and the geotextile. Backfilling is a technique of raising the water level upward through the test specimen.

Close the bleed valve once water flows from it. Continue to fill the apparatus with de-aired water until the water level reaches the overflow.

With water flowing into the system through the water inlet, adjust the discharge pipe along with the rate of water flowing into the apparatus to obtain 50-mm or 2-in. head of water on the geotextile. This is the head, h , under which the test will be performed.

Submerge a tube attached to a source of vacuum to the surface of the geotextile. Apply a slight vacuum to remove any trapped air that may be in or on the specimen. If necessary, readjust the head to 50 mm after removing the vacuum.

Record the values of time, t ; quantity of flow, Q ; and water temperature, holding the head at 50 mm. At least five sets of data per specimen should be collected. Determine an average value of permittivity for the specimen from the five or more sets of data.

Repeat the procedure on the three remaining specimens that have already been conditioned.

B.2.11 Calculations

Using Equation B-1, calculate the permittivity, Ψ :

$$\Psi = QR_t/hAt \qquad \text{Equation B-1}$$

where:

Q = quantity of flow, in cubic millimeters

h = the head of water on the specimen, in millimeters

A = cross-sectional area of test area of specimen in square millimeters

t = time for flow, Q, in seconds

R_t = temperature correction factor determined using Equation B-2

$$R_t = u_t/u_{20C} \qquad \text{Equation B-2}$$

where

u_t = water viscosity at test temperature in millipoise

u_{20C} = water viscosity at 20° C (68° F) in millipoise

Using Equation B-3, calculate quantity of flow per time unit of flow through a cross-sectional unit area, Q/tA:

$$Q/tA = \Psi\ h/R_t \qquad \text{Equation B-3}$$

Using Equation B-4, calculate the equivalent Darcy coefficient of permeability or hydraulic conductivity, k :

$$k = L\ \Psi \qquad \text{Equation B-4}$$

where

k = equivalent Darcy coefficient of permeability

L = nominal thickness of a geotextile

Repeat for the five sets of data per specimen at 50 mm head.

Determine the average for the individual specimens tested.

Determine the average for the four specimens tested.

Determine the standard deviation and coefficient of variation for the four specimens tested.

B.2.12 Report

The following shall be included in the report of the test results:

a. State that the specimens were tested according to this method.

b. State the results of the permittivity and quantity of flow per unit of time through a cross-sectional unit area for the individual specimens and the average of the four specimens tested.

Note 2: In the constant head procedure, if a head other than 50 mm is used for laminar flow, state what the head value was.

c. State any variation from the described test method.

d. The equivalent Darcy coefficient of permeability can be reported as per section B.2.10.

e. State the specimen size and water flow through dimensions of the test apparatus.

B.2.13 Precision and Accuracy

Accuracy--No statement concerning accuracy is made at this time because a statistically significant amount of data is not available for evaluation.

Precision--Precision of this method is being established by ASTM Committee D 35.

B.3 Percent Open Area Determination Procedure For Woven Geotextiles

A small section of the fabric to be tested should be installed in a standard 5- by 5-cm (2- by 2-in.) slide cover so that it can be put into a slide projector and projected onto a screen. Any method to hold the fabric section and maintain it perpendicular to the projected light can be used.

The slide projector should be placed level to eliminate any distortion of the fabric openings. After placing the slide in the projector and focusing on a sheet of paper approximately 2.4 to 3 m (8 to 10 ft) away, the opening outlines can be traced.

Draw a rectangle of about 0.04- to 0.09-m^2 (0.5 to 1.0-ft^2) area on the "projection screen" sheet of paper to obtain a representative area to test; then trace the outline of all openings inside the designated rectangle.

After removing the sheet, find the area of the rectangle, using a planimeter. If necessary, the given area may be divided to accommodate the planimeter.

Find the total area of openings inside the rectangle, measuring the area of each with a planimeter.

Compute percent open by the equation:

$$\text{Percent Open Area} = \frac{\text{Total Area Occupied by Openings}}{\text{Total Area of Test Rectangle}} \times 100$$

B.4 New York State Department of Transportation Sieving Test For Particle Retention and Equivalent Opening Size (EOS) of Engineering Fabrics

B.4.1 Introduction

This test involves sieving glass beads through an engineering fabric to determine the equivalent diameter of its pore openings and its EOS.

B.4.2 Apparatus and Supplies

The following apparatus and supplies are required:

a. "Ro-Tap" or other rotary sieve shaker.

b. Pan, cover, and 8-in. sieves without wire screen, or with 1 in. or larger openings.

c. Spherical glass beads[a] in each of the following sieve sizes:

U. S. Bureau of Standards Sieve Size No. (ASTM E 11)
18-20
35-40
50-60
70-80
80-100
120-140
170-200

d. Balance (±0.01 g accuracy).

e. Engineering fabric samples 25.4 cm (10 in.) in diameter.

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[a] Available through: Ferro Corporation
Cataphote Division
PO Box 2369
Jackson, MS 39205
(601) 939-4631

f. Four Staticmaster Ionizing Units.[a]

B.4.3 Procedure

Using the engineering fabric samples of interest, do the following:

a. Install the Staticmaster units on the center of cover and equidistant around the perimeter of the top sieve frame, as shown in Figure B-2. Secure the fabric sample between two sieve frames or in such a way that no beads pass between fabric and frame. Record the weight of the fabric sample and frame.

b. Place 50 g (1.8 oz) of the smallest-size glass beads on the fabric.

c. Install cover and pan on the sieve frames and place sieve nest in the sieve shaker. Shake for 10 minutes.

d. Record weight of glass beads caught in pan.

e. If the fabric has beads trapped internally (possible for some fabrics, especially felted nonwovens), break the sieve nest and replace the fabric sample. If not, the same fabric sample may be reused.

f. Repeat Steps b through d for increasing glass bead sizes.

g. If desired, a particle size (fabric opening) distribution curve may be drawn for the fabric. However, the fabric EOS is the U. S. Bureau of Standards sieve number for the first glass bead size having 5 percent or less pass the fabric when sieving successively coarser bead sizes. This value is approximately the D_5 size of the fabric.

Note 1: The U. S. Army Corps of Engineers procedure uses a 20-min shaking time, which may give a different EOS value.

Note 2: After about 10 to 12 hr of shaking, glass beads should be size-checked by sieving with conventional testing sieves. Broken or otherwise out-of-size beads should be discarded.

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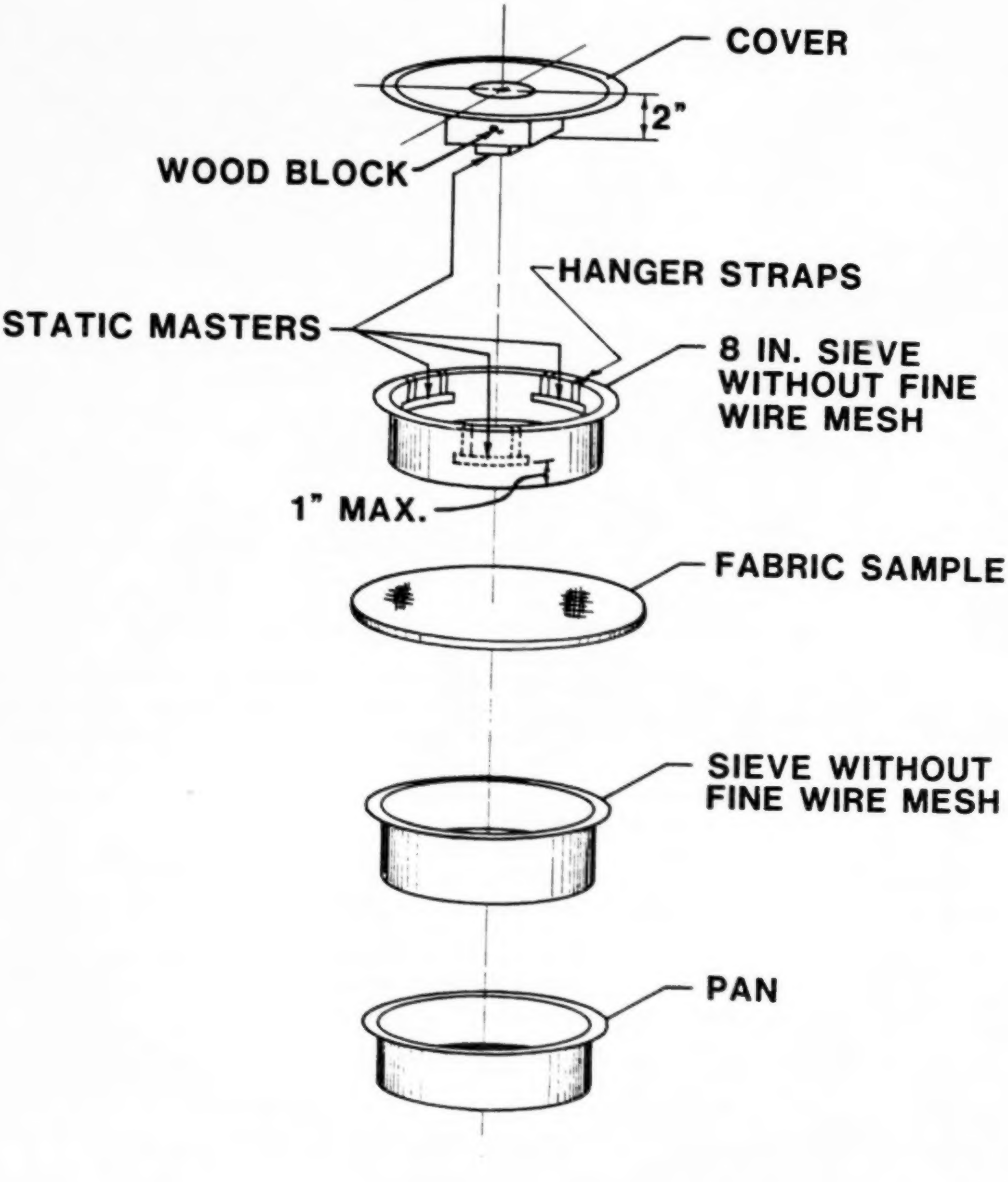
[a] Available through: Staticmaster Ionizing Unit
Model No. 2U500
Nuclear Products Company
2519 North Merced Avenue
South El Monte, CA 91733
PO Box 5178
El Monte, CA 91734
(213) 283-2603

FIGURE B-2

FABRIC EOS SIEVING TEST APPARATUS


COVER
2"
WOOD BLOCK
HANGER STRAPS
STATIC MASTERS
8 IN. SIEVE WITHOUT FINE WIRE MESH
1" MAX.
FABRIC SAMPLE
SIEVE WITHOUT FINE WIRE MESH
PAN

B.5 U.S. Army Corps of Engineers-Type Engineering Fabric-Soil Gradient Ratio Test Procedure

A constant-head permeability test shall be performed in a permeameter cylinder similar to that shown in Figure B-3. Soil specimens to be tested shall be representative in classification and density of those materials to be protected. If actual soil specimens are unavailable or comparative performance evaluations are desired, a test soil can be prepared using ASTM Standard C 190 Ottawa 20-30 sand and Vicksburg, Mississippi, silt loess. The loess should be premixed (dry) with the sand, and testing should be conducted with increasing percentages of silt by weight (i.e., 0, 5, 10, 15, 20, 25, 30 percent, etc.).

A piece of hardware cloth with 6-mm (0.25-in.) openings shall be placed beneath the fabric specimen to support it. The fabric and hardware cloth shall be clamped between permeameter flanges and sealed so that no soil or water can pass around the edges of the fabric. Care should be taken to avoid getting any sealant used on the portion of the fabric inside the cylinder.

The soil specimen shall have a length of 102 mm (4 in.), and shall be placed in a way that achieves a uniform specimen of the desired density. Piezometer taps shall be placed 25 mm (1 in.) below the fabric and 25 mm (1 in.), 50 mm (2 in.), and 75 mm (3 in.) above the fabric.

Tap water is acceptable for testing and shall be pumped slowly into the bottom of the units to saturate the soil. An operating gradient to produce optimum flow should be maintained by adjusting the outflow standpipe elevation. In comparative fabric evaluations, standpipe elevation should remain constant for a given soil mixture of interest and all testing should be conducted with the outflow standpipe above the top of the soil specimen.

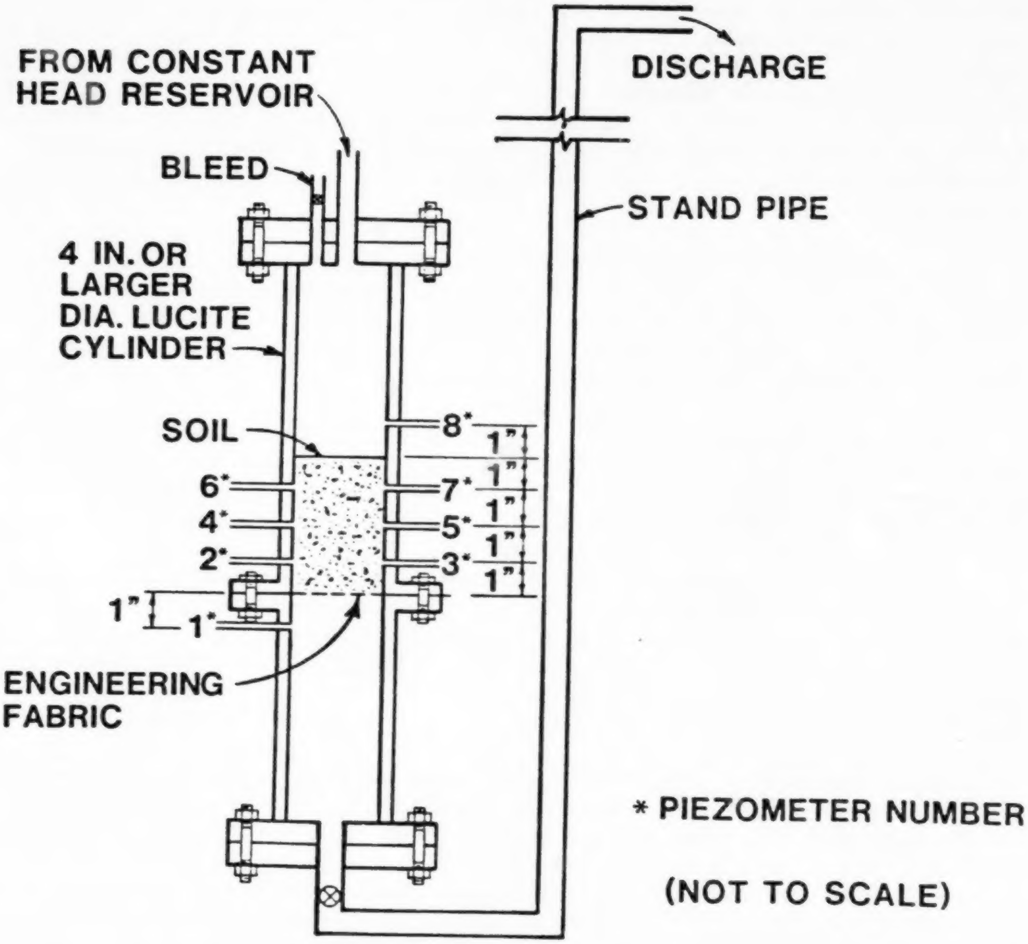
After the test is started, a flow rate determination and piezometer readings should be taken. Piezometer readings should be taken every 15 minutes until they stabilize; then another flow rate determination should be made. After piezometer readings stabilize, the tap water shall be permeated through the soil specimen for a continuous period of 24 hr. Final piezometer readings and a flow rate determination should be made at the end of the 24-hr period. The gradient ratio (GR) shall be determined from the readings taken at the end of the 24-hr period.

The final GR is determined from the final piezometer readings and is the hydraulic gradient through the lower 25 mm (1 in.) of soil plus fabric (i_1) divided by the hydraulic gradient through the adjacent 50 mm (2 in.) of soil, between 25 mm (1 in.) and 75 mm (3 in.) above the fabric (i_2) (see Figure B-4) such that:

$$GR = \frac{i_1}{i_2} = \frac{\frac{H_1}{L_1}}{\frac{(H_2 + H_3)}{(L_2 + L_3)}}$$

FIGURE B-3

DETAIL OF CONSTANT-HEAD PERMEAMETER TEST DEVICE USED FOR GRADIENT RATIO TESTING

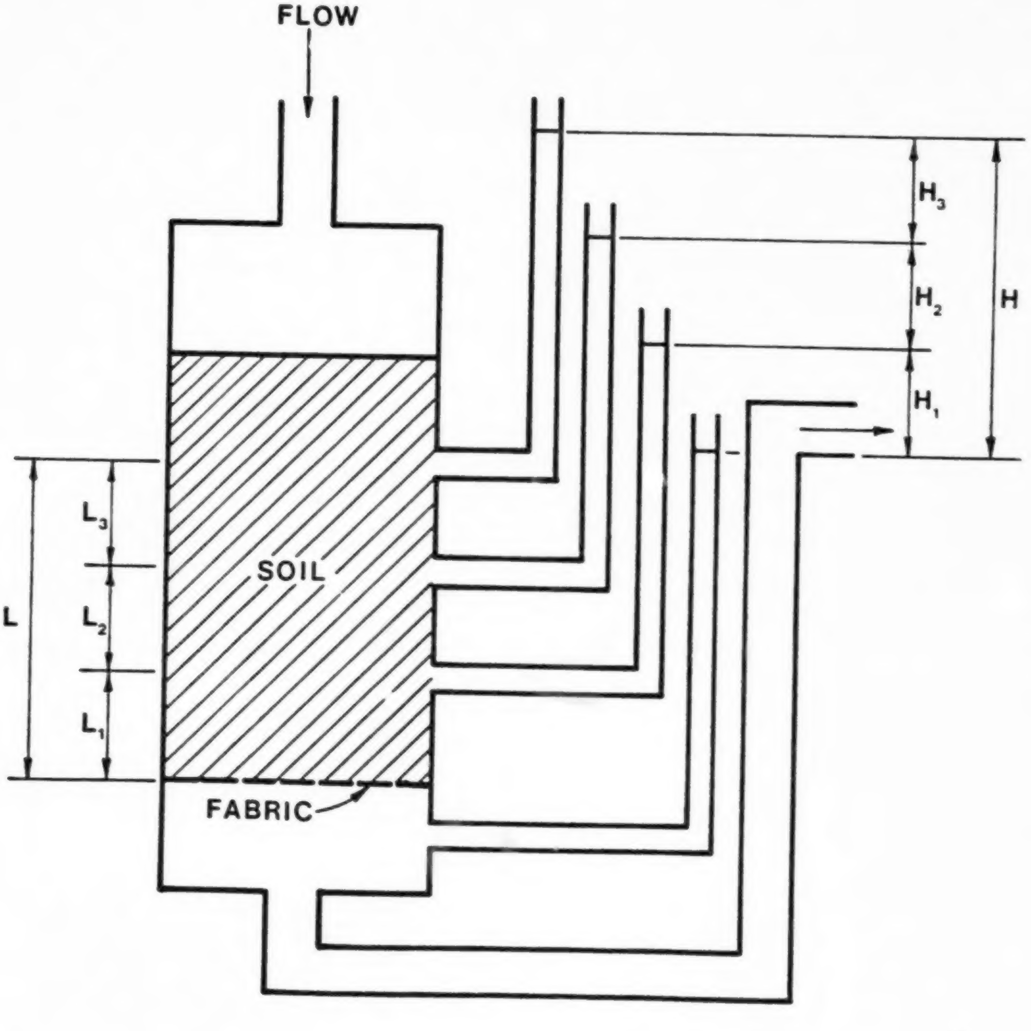

FROM CONSTANT HEAD RESERVOIR
DISCHARGE
BLEED
STAND PIPE
4 IN. OR LARGER DIA. LUCITE CYLINDER
SOIL
8*
7*
6*
5*
4*
3*
2*
1*
1"
1"
1"
1"
1"
1"
ENGINEERING FABRIC
* PIEZOMETER NUMBER
(NOT TO SCALE)

If it is desired to determine the extent of silt migration, soil samples should be taken over intervals of 0 to 6 mm (0 to 0.25 in.), 6 to 25 mm (0.25 to 1.0 in.), 25 to 50 mm (1.0 to 2.0 in.), and 50 to 76 mm (2.0 to 3.0 in.) above the fabric. These samples may be oven-dried and sieved, and particle size distributions may be compared with those of the pretest soil.

The initial and final permeability of the soil-fabric system, or any intermediate values for the system, may be determined from the flow readings and corresponding piezometer readings.

FIGURE B-4

METHOD OF DETERMINING U. S. ARMY CORPS OF ENGINEERS SOIL-FABRIC GRADIENT RATIO


FLOW
H3
H2
H
H1
L3
L
L2
SOIL
L1
FABRIC

$L_1 = L_2 = L_3 = 1.0$ IN.

$$\text{GRADIENT RATIO} = \frac{\dfrac{H_1}{L_1}}{\dfrac{(H_2 + H_3)}{(L_2 + L_3)}}$$

APPENDIX C

GLOSSARY OF TERMS

ABRASION RESISTANCE - The ability of a fabric surface to resist wear by friction.

ABSORPTION - The process of a gas or liquid being incorporated into a fabric.

ACID RESISTANCE - See "chemical stability."

ALKALI RESISTANCE - See "chemical stability."

AOS - See "apparent opening size."

APPARENT OPENING SIZE (AOS) - A term sometimes used instead of equivalent opening size.

ARMOR - A protective covering.

BIAS - A direction diagonal to the warp and fill.

BIAXIAL TENSILE TEST - A tensile test in which a fabric specimen is subjected to tensile forces in two directions 90 degrees to each other, usually the machine and cross-machine directions.

BIOLOGICAL STABILITY - Ability to resist degradation from exposure to microorganisms.

BLINDING - Plugging of a fabric by partial penetration of particles into surface pores (i.e., the formation of a surface crust or cake).

BONDING - A process of binding fabric fibers by means of adhesive or by welding with heat and pressure.

BURST STRENGTH - The resistance of a fabric to rupture from pressure applied at right angles to the plane of the fabric under specified conditions, usually expressed as the pressure causing failure. Burst results from tensile failure of the fabric.

CHEMICAL BONDING - A bonding process in which the individual fibers in the fabric web are cemented together by chemical interaction.

CHEMICAL STABILITY - Ability to resist chemicals such as acids, bases, solvents, oils and oxidation agents, and chemical reactions, including those catalyzed by light.

CLOGGING - The plugging of a fabric by deposition of particles within the fabric pores (other than blinding).

COMPRESSIBILITY - Property of a fabric describing the ease with which it can be compressed normal to the plane of the fabric.

CONSTRUCTABILITY - See "workability."

CONSTRUCTION, FABRIC - The way the fibers, filament, and/or yarns are oriented and bonded to produce a fabric.

CREEP, CYCLIC - Unrecoverable strain accumulated with repeated loading.

CREEP, STATIC - Increasing strain at constant stress.

CROSS DIRECTION (CROSS-MACHINE DIRECTION) - The axis within the plane of a fabric perpendicular to the direction of motion in the final forming step.

CUTTING RESISTANCE - The resistance of the fabric or fiber to cutting when struck between two hard objects.

DENIER - A weight-per-unit-length measure of any linear material numerically equal to the weight in grams of 9,000 m of the material.

EOS - See "equivalent opening size."

EPOXY BONDING - A bonding process in which the fabric web is impregnated with epoxy resin that serves to coat and cement the fibers together.

EQUIVALENT OPENING SIZE (EOS) - A measure of the size of the largest openings in a geotextile. The EOS is the "retained on" sieve size of narrowly sized, rounded sand or glass beads, of which 5 percent or less by weight passes through the fabric when the particles are shaken on the fabric in a prescribed manner. The EOS is usually expressed as the U. S. Standard sieve number, but it may also be expressed in millimeters.

FABRIC, BONDED - A textile structure wherein the fibers are bonded together with an adhesive or by welding with heat and pressure.

FABRIC, KNITTED - Textile made up of loops of fibers connected by straight segments.

FABRIC, NONWOVEN - A textile structure produced by bonding or interlocking of fibers, or both, accomplished by mechanical, chemical, or solvent means and combinations thereof, excluding woven and knitted fabrics.

FABRIC, WOVEN - A textile structure comprising two or more sets of filaments or yarns interlaced in such a way that the elements pass each other essentially at right angles and one set of elements is parallel to the fabric axis.

FATIGUE RESISTANCE - The ability to withstand stress repetitions without suffering a loss in strength.

FELT - A sheet of matted fibers made by a combination of mechanical and chemical action, pressure, moisture, and heat.

FIBER - Basic element of fabrics and other textile structures, characterized by having a length at least 100 times its diameter or width that can be spun into a yarn or otherwise made into a fabric.

FIBRILLATED YARN - A yarn made from a film which has been nicked and broken up into fibrous strands that are then bundled together. The fibers can still be partially attached to one another.

FILAMENT - A fiber of extreme length. Sometimes called "continuous filaments."

FILL - Fibers or yarns placed at right angles to the warp or machine direction in a woven fabric.

FILTER CAKE - A thin layer of fine soil particles accumulated in the soil adjacent to the fabric as a result of smaller soil particles being washed through the soil pores.

FILTRATION - The process of allowing water to easily escape from soil while retaining soil in place.

FLEXIBILITY - The ability to bend around a small radius with the application of only a small flexural stress. Low stiffness.

FREEZE-THAW RESISTANCE - Ability to resist degradation caused by freeze-thaw cycles.

FRICTION ANGLE - An angle, the tangent of which is equal to the ratio of the friction force per unit area to the normal stress between two materials.

GEOTEXTILE - Any permeable synthetic textile used in geotechnical engineering.

GRAB TENSILE STRENGTH - A modified tensile strength of a fabric. The strength of a specific width of fabric together with the additional strength contributed by adjacent areas. Typically, grab strength is determined on a 100-mm- (4-in.-) wide strip of fabric, with the tensile load applied at the midpoint of the fabric width through 25-mm- (1-in.-) wide jaw faces.

GRADIENT RATIO - The ratio of the average hydraulic gradient across the fabric and the 25 mm (1 in.) of soil immediately next to the fabric to the average hydraulic gradient across the 50 mm (2 in.) of soil between 25 and 75 mm (1 and 3 in.) above the fabric, as measured in a constant-head permeability test.

HEAT BONDING - A process by which fabric filaments are welded together at their contact points by subjection to a relatively high temperature.

KEVLAR - The registered trademark for a manufactured fiber in which the fiber-forming substance is aramid or aromatic polyamide.

LATERAL DRAINAGE ABILITY - The capacity of a fabric to transmit water flow within the plane of the fabric.

MACHINE DIRECTION - The axis within the plane of the fabric parallel to the direction in which a fabric is processed onto rolls as the final step of production.

MELT BONDING - See "heat bonding."

MODULUS - A measure of the resistance to elongation under load. The ratio of the change in tensile load per unit width to the corresponding change in strain.

MODULUS, OFFSET TANGENT - A tensile stress-strain modulus obtained using a straight line to represent the stress-strain curve drawn parallel to and offset by a prescribed distance from a line tangent to the initial portion of the actual stress-strain curve.

MODULUS, SECANT - A tensile stress-strain modulus obtained using a straight line (to represent the stress-strain curve) drawn from the origin through a coordinate representing a stress measured at a specified strain.

MONOFILAMENT - A single filament of a man-made fiber, usually of a denier higher than 15.

MULTIFILAMENT - A yarn consisting of many continuous filaments or strands.

NAP - A hairy or downy surface on a fabric.

NONWOVEN FABRIC - A textile structure produced by bonding or interlocking of fibers, or both, accomplished by mechanical, chemical, or solvent means.

NEEDLE PUNCHING - Subjecting a web of fibers to repeated entry of barbed needles that compact and entangle individual fibers to form a fabric.

NEEDLED FABRIC - A fabric constructed by needled punching.

PENETRATION RESISTANCE - The fabric property determined by the force required to penetrate a fabric with a sharp pointed object. Initial penetration is by separating the fibers. Further penetration is essentially a tearing process.

PERCENT OPEN AREA - The net area of a fabric that is not occupied by fabric filaments, normally determinable only for woven and nonwoven fabrics having distinct visible and measurable openings that continue directly through the fabric.

PERMEABILITY (LONGITUDINAL OR IN PLANE) - The fabric property that permits a fluid (normally water) to be transmitted in the plane of the fabric. See "transmissivity."

PERMEABILITY (TRANSVERSE) - The fabric property that allows a fluid (normally water) to pass through perpendicular to the plane of the fabric. See "permittivity."

PERMEABILITY, COEFFICIENT OF - A measure of the permeability of a porous media such as soil or geotextile to water. It is the ratio of discharge velocity to the hydraulic gradient under laminar flow conditions. Also referred to as the Darcy coefficient.

PERMITTIVITY - For a fabric, the volumetric flow rate of water per unit of cross-sectioned area, per unit head, under laminar flow conditions, in the direction perpendicular to the plane of the material.

PIPING - The process of soil removal resulting from seepage, in which tunnel-like openings or pipes form in the soil mass.

PLANE STRAIN - A loading condition where strains in the plane of the fabric occur in only one direction.

PLUGGING - The partial or total closure of fabric pores as a result of particle or chemical deposition or biological growth within or on a fabric. Plugging can consist of clogging, blinding, or both.

POLYESTER FIBER - A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 percent by weight of an ester of dihydric alcohol and terephthalic acid.

POLYETHYLENE FIBER - A manufactured fiber in which the fiber-forming substance is an olefin made from polymers or copolymers of ethylene.

POLYMER - A high molecular chainlike structure from which man-made fibers are derived: polymers are produced by linking together molecular units called monomers, consisting predominantly of nonmetallic elements or compounds.

POLYPROPYLENE FIBER - A manufactured fiber in which the fiber-forming substance is an olefin made from polymers or copolymers of propylene.

PORE SIZE - The size of an opening between fabric fibers. Because of the variability of opening sizes for different fabrics, the equivalent opening size (EOS) is used to determine the approximate size of the largest pores of fabric.

PUNCTURE RESISTANCE - Resistance to failure of a fabric from a blunt object applying a load over a relatively small area. Failure results from tensile failure of the fibers.

REINFORCEMENT - Strengthening of a soil-fabric system by contributions of the fabric inclusion.

RESIN BONDING - A bonding process in which fabric web is impregnated with a resin that serves to coat and cement the fibers together.

SCRIM - A woven fabric to which nonwoven fibers are bonded or needle-punched to form a composite fabric.

SEPARATION - Function of fabric as a partition between two adjacent materials to prevent mixing of the two materials.

SLIT-FILM FILAMENT - A filament with a width many times its thickness.

SOIL-FABRIC FRICTION - The resistance to sliding between engineering fabric and soil, excluding the resistance from soil cohesion. Soil-fabric friction is usually quantified in terms of a friction angle.

SPECIFIC GRAVITY - The ratio of the density of a fabric to the density of water obtained by weighing both items in air. A specific gravity of less than one implies that the fabric will float.

SPUN - a. A yarn (bundle of fibers) made from staple fibers interlaced and twisted together.

b. The process of extrusion through a spinneret to make a filament.

SPUNBONDED - Any nonwoven fabric made in a continuous line process in which filaments are extruded, drawn formed into a loose web, and bonded. The bonding process can be mechanical, thermal, or chemical.

STAPLE FIBERS - Fibers having a short length, typically 25 to 100 mm (1 to 4 in.).

STIFFNESS - The ability of a fabric to resist bending when flexural stress is applied.

STRENGTH - Load and failure. Depending on usage, load may be expressed in stress, force per unit width, or force.

SURVIVABILITY - The ability of a fabric to be placed and to perform its intended function without undergoing degradation.

TANGENT MODULUS - A tensile stress-strain modulus obtained using a straight line (to represent the stress-strain curve) drawn tangent to a specified portion of the stress-strain curve.

TENACITY, BREAKING - The breaking load of a fiber or yarn, in force per unit linear density of the unstrained specimen, customarily expressed as grams-force per denier (gf/den.) or grams-force per tex (gf/tex).

KNOT BREAKING STRENGTH - The breaking strength of a strand with a knot tied in the portion of the specimen between the clamps.

TAPE FILAMENT - A slit-film filament.

TENSILE MODULUS - See "tensile stress-strain modulus."

TENSILE STRENGTH - The strength shown by a fabric subjected to tension as distinct from torsion, compression, or shear.

TENSILE STRESS-STRAIN MODULUS - A measure of the resistance to elongation under stress. The ratio of the change in tensile stress to the corresponding change in strain.

TENSILE TEST - A test that subjects fabric to tensile forces and measures resulting stresses and strains, which are used to identify the stress-strain behavior of the fabric. There are several variations of the tensile test, the most widely used of which are the grab test, cut-strip test, wide-width test, and the raveled strip test. All of the above tests are considered uniaxial tensile tests.

TENSILE TEST, UNIAXIAL - A tensile test in which a fabric specimen is subjected to tensile forces in one direction only.

THERMAL STABILITY - The ability of fibers and yarns to resist changes in properties at extreme temperatures.

THICKNESS - The normal distance between two surfaces of a fabric. Thickness is usually determined as the distance between an anvil, or base, and a presser foot used to apply a specified compressive stress.

TOUGHNESS - The property of a fabric by which it can absorb work energy. It is proportional to the area under the load-elongation curve from origin to breaking point.

TRANSMISSIVITY - For a fabric, the volumetric flow rate of water per unit width per unit head under laminar flow conditions in the longitudinal direction through the material.

ULTRAVIOLET (UV) RADIATION STABILITY - The ability of fabric to resist deterioration from exposure to sunlight. Actinic resistance.

WARP - Fibers or yarns parallel to the fabric machine direction in a woven fabric.

WEB - The sheet or mat of fibers or filaments before bonding or needle-punching to form a nonwoven fabric.

WEIGHT, FABRIC - The mass of a fabric expressed in weight per unit area.

WICKING - The process whereby a fabric raises water above a free water surface by capillary action.

WORKABILITY - The ease with which a fabric can be controlled, handled, laid and seamed.

YARN - A generic term for a continuous strand of textile fibers, filaments, or material in a form suitable for weaving or otherwise intertwining to form a textile fabric.

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